Phytoremediation of TCE in a Shallow Alluvial Aquifer: A Field Demonstration

Gregory J. Harvey, U.S. Air Force

Objective

To demonstrate in the field the ability of purposefully planted eastern cottonwood trees to help remediate shallow trichloroethylene (TCE) contaminated ground water.

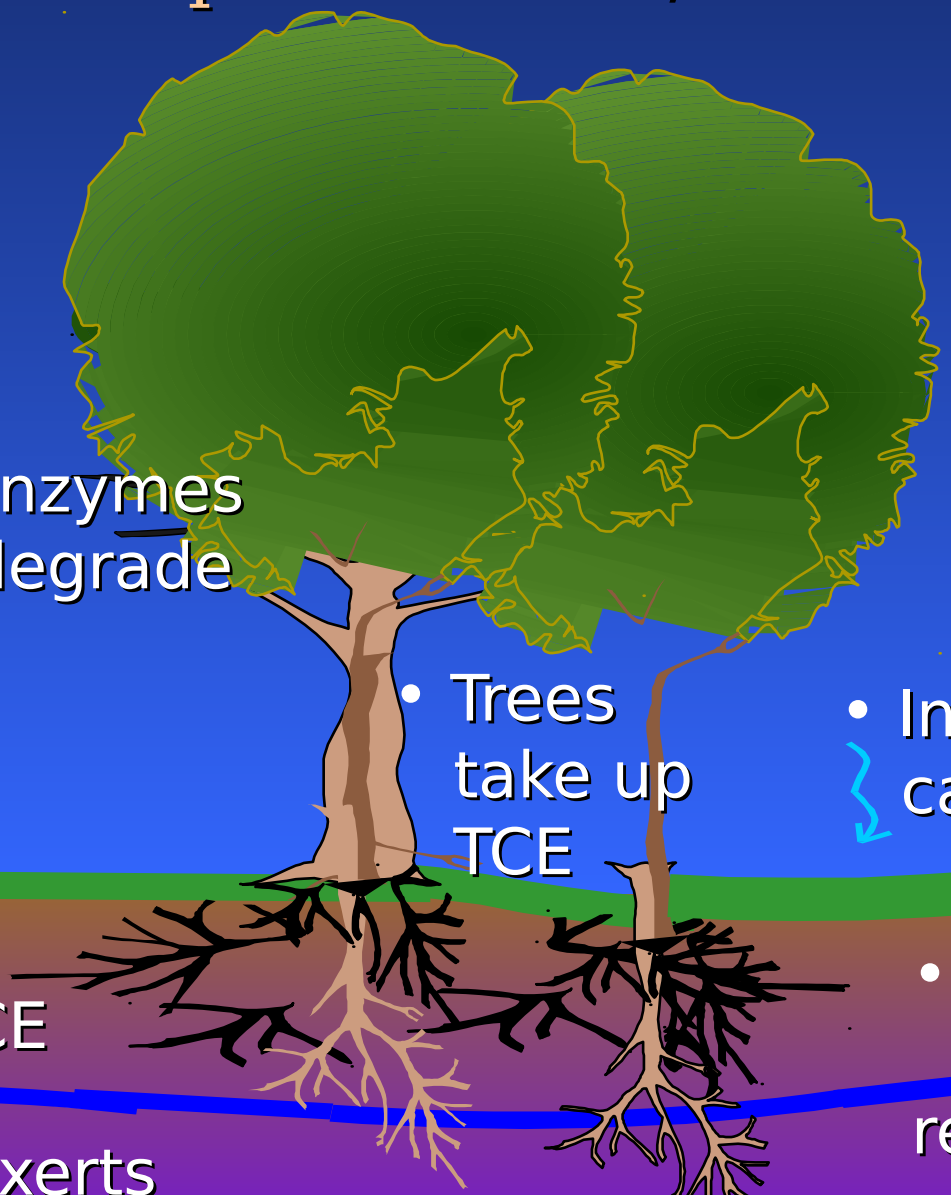
Acknowledgments

- Environmental Security Technology Certification Program of the Department of Defense
- Superfund Innovative Technology Evaluation Program of the U.S. Environmental Protection Agency
- Aeronautical Systems Center/Environmental Management Directorate at Wright Patterson AFB

Talk Outline

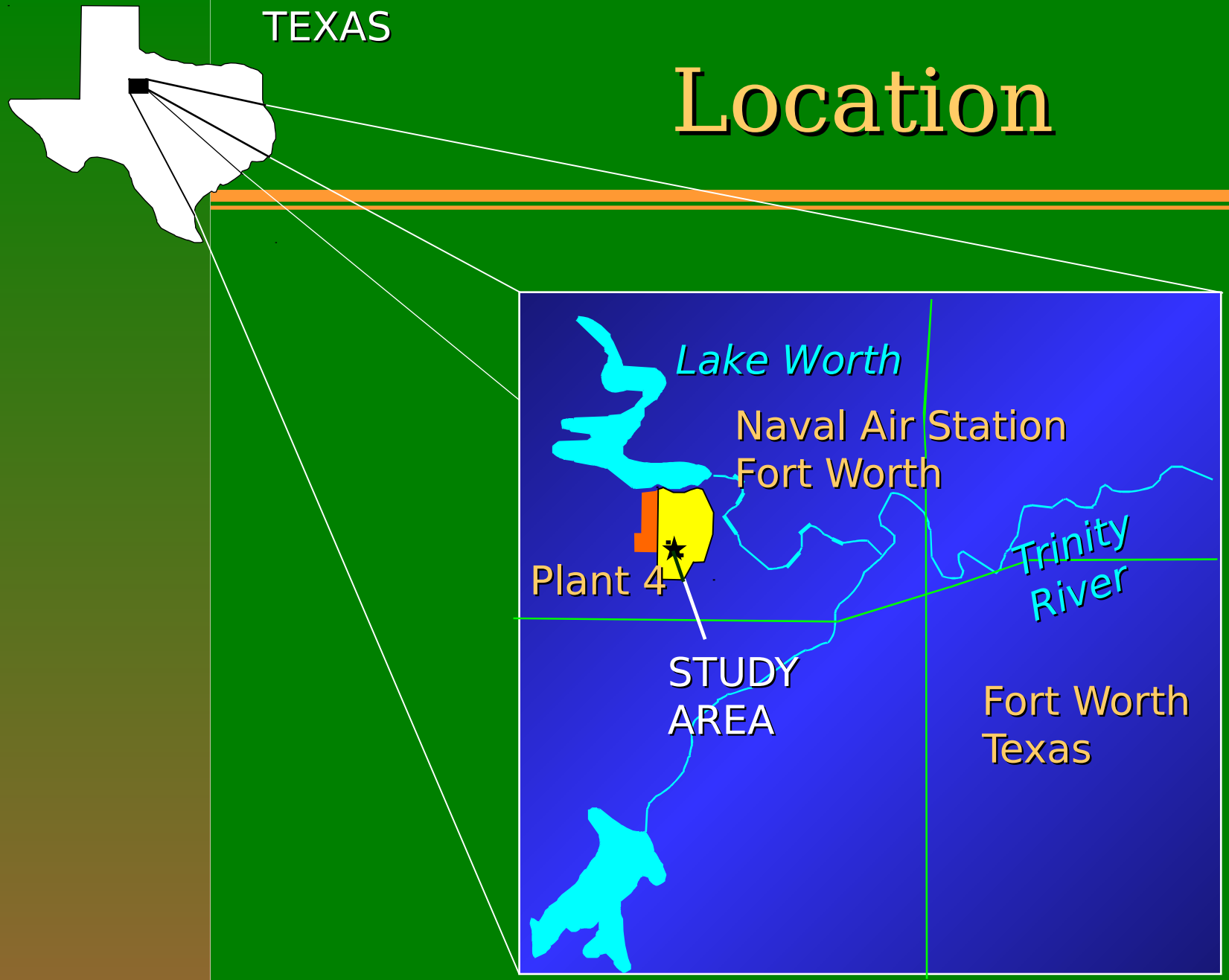
- Conceptual Model
- Background
- Results to Date
- Regulatory Issues

Conceptual Model / Treatment System

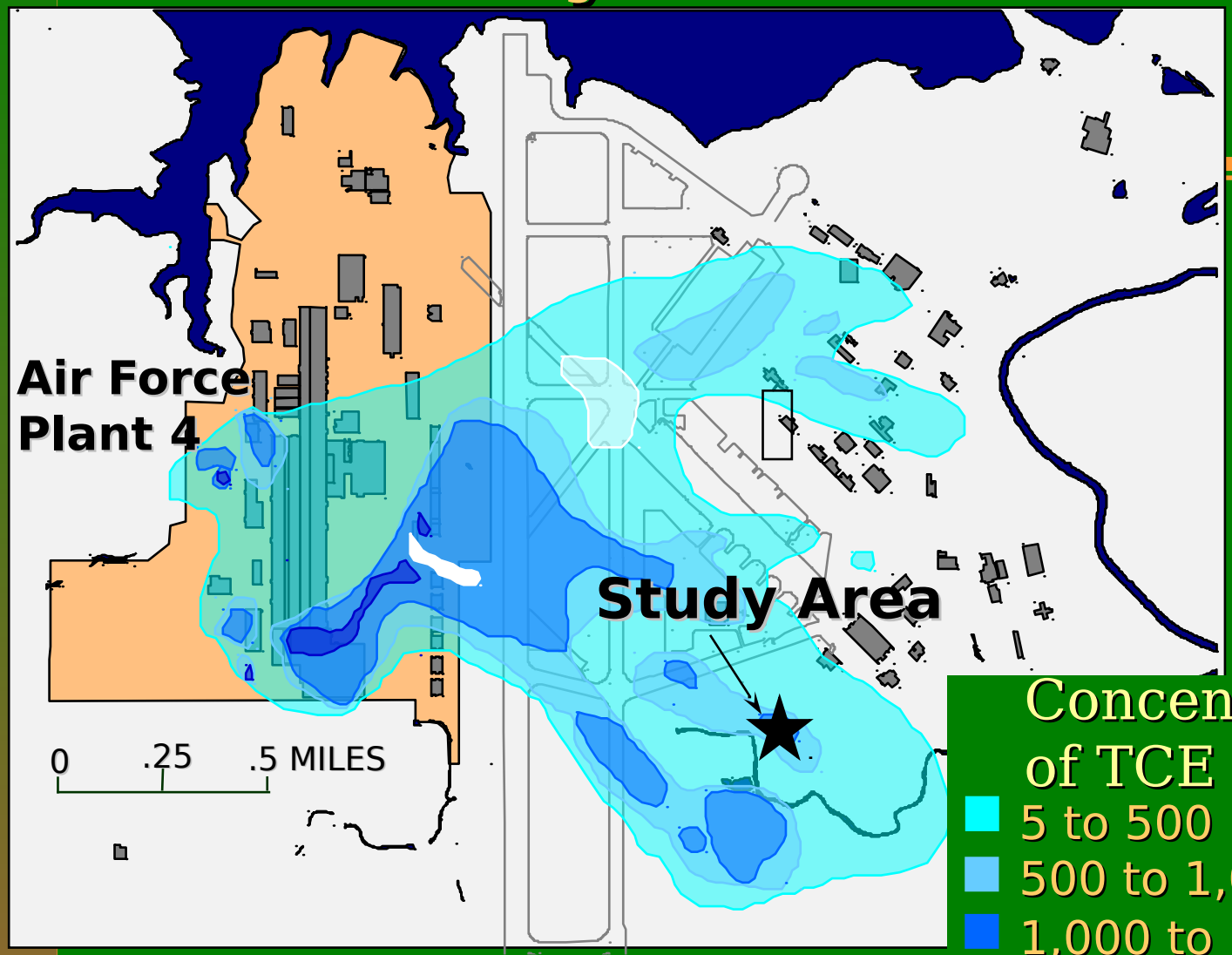


- Tree enzymes help degrade TCE
- Trees take up TCE
- Infiltration causes dilution
- Microbes degrade TCE
- Organic matter creates reducing conditions in the
- Pumpage exerts hydraulic control
- TCE sorbs onto additional organic

Location


TEXAS
Lake Worth
Naval Air Station
Fort Worth
Plant 4
Trinity
River
STUDY
AREA
Fort Worth
Texas

Study Area


Air Force
Plant 4
Study Area
0 .25 .5 MILES
Concentration
of TCE in ug/L
5 to 500
500 to 1,000
1,000 to 10,000
>10,000 <100,000

Site Hydrology

- Aquifer — Silty Sand, 2 - 5 feet thick, Aer
- Water Table — 8 - 14 feet bls
- Recharge from Precipitation — 2.5 in/y

Scope and Approach

- What Affect Do The Trees Have On The Dissolved TCE Plu
  - Monitor / model changes in ground-water levels
  - Monitor ground-water geochemistry
  - Compute changes in the mass flux of TCE across the downgradient end of the site

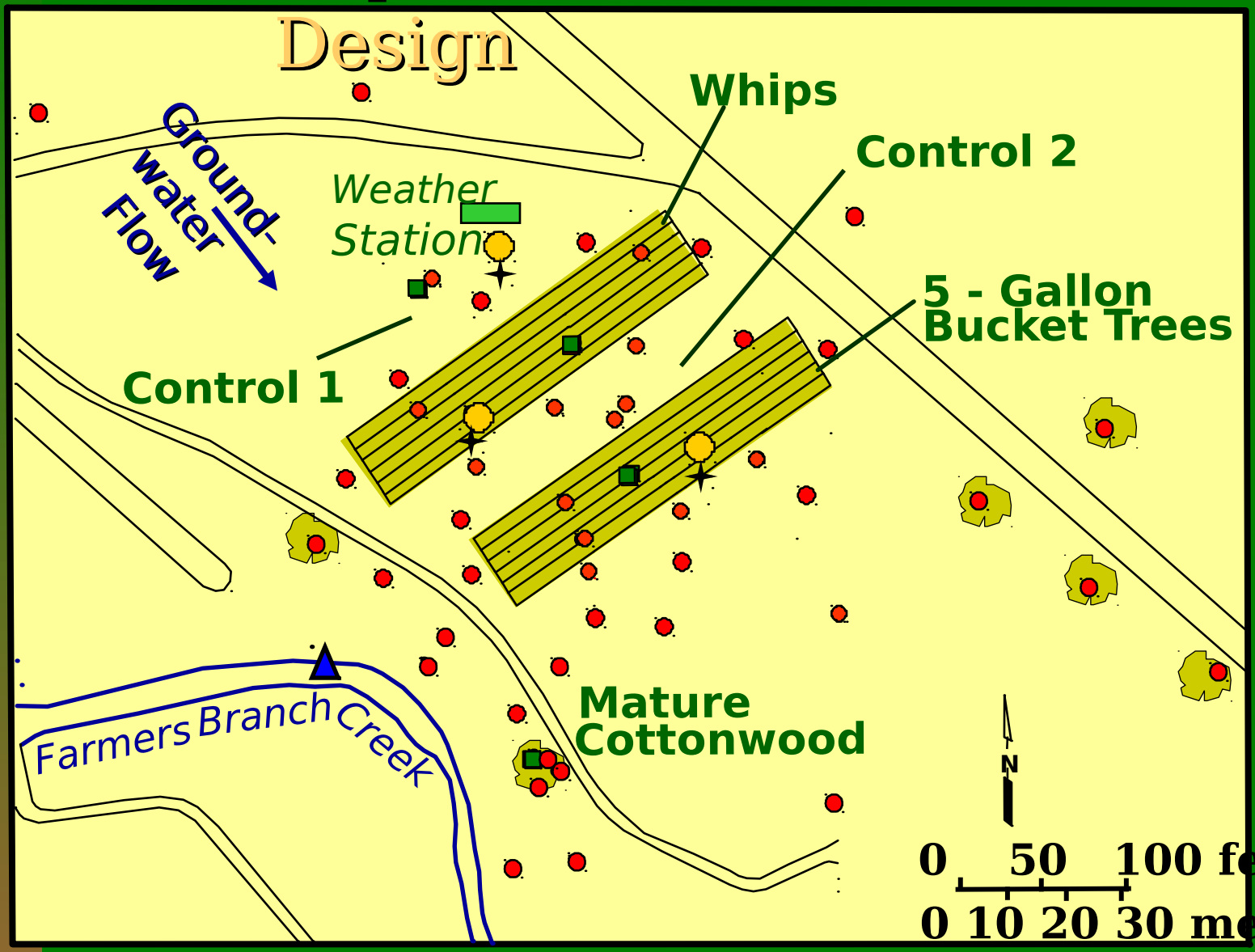
Scope and Approach

- What Is The Fate Of TCE At The Site?
  - Compute tree transpiration rates
  - Investigate enzymatic activity of the trees
  - Investigate microbial activity in the soils
  - Compare concentrations of daughter and parent compounds in the ground water, soil, and tree tis

Scope and Approach

- How Practical Is The Technology?
  - Document how long it takes for the trees to affec the plume
  - Compare root development between trees of different ages
  - Document how much it costs

Experimental Design



Root Growth

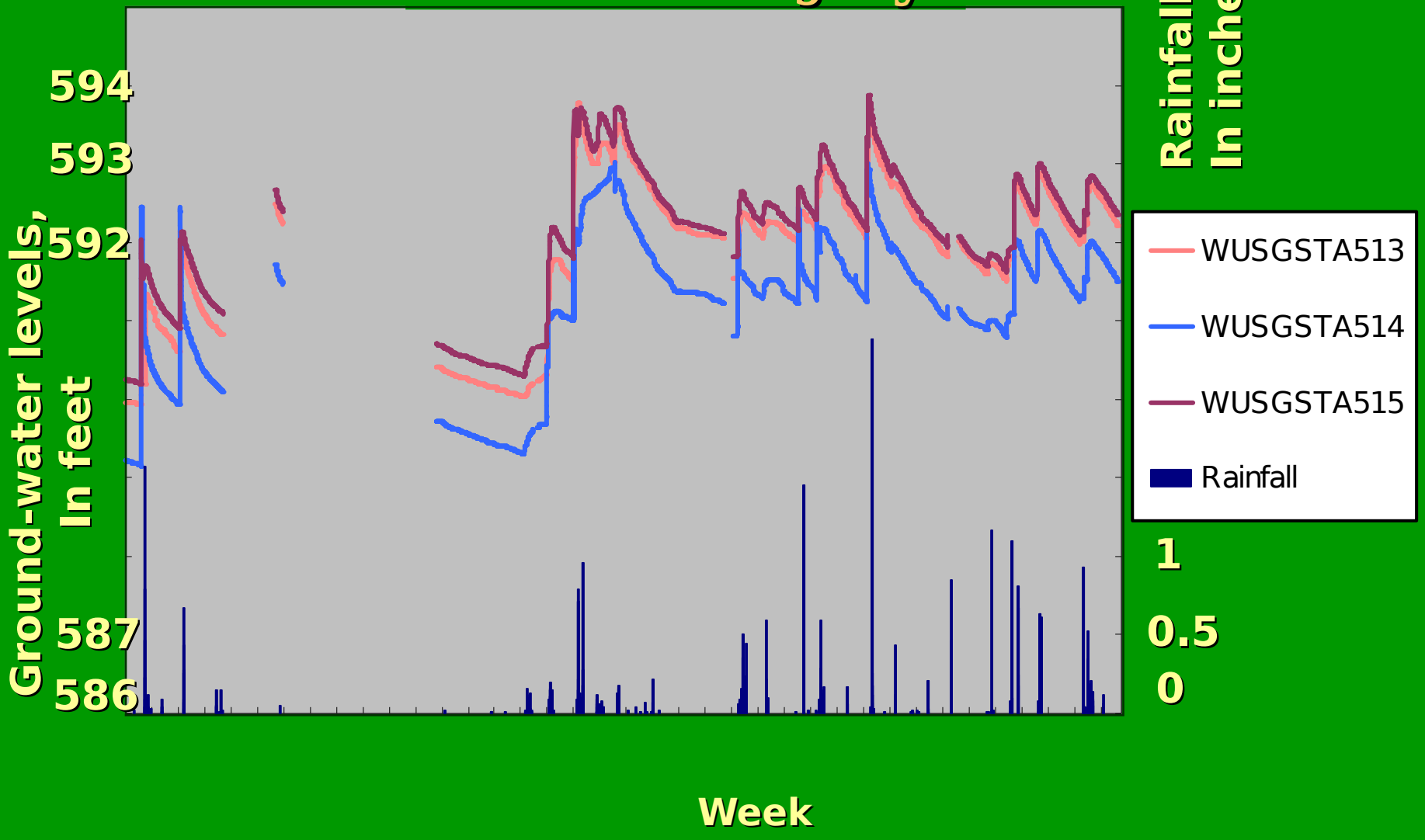
- Roots in both tree stands
  reached the water table
  within the first two growing seasons

- Notable amount of roots
  have entered the well screens

- Five-gallon bucket trees

(Hendrick, Univ. of Georgia, written commun., 1997)

Ground-water levels and Rainfall
October 1996 - July 1997



Transpiration (Summer 1997)

- WHIPS
  6.2 kg/day (mean)

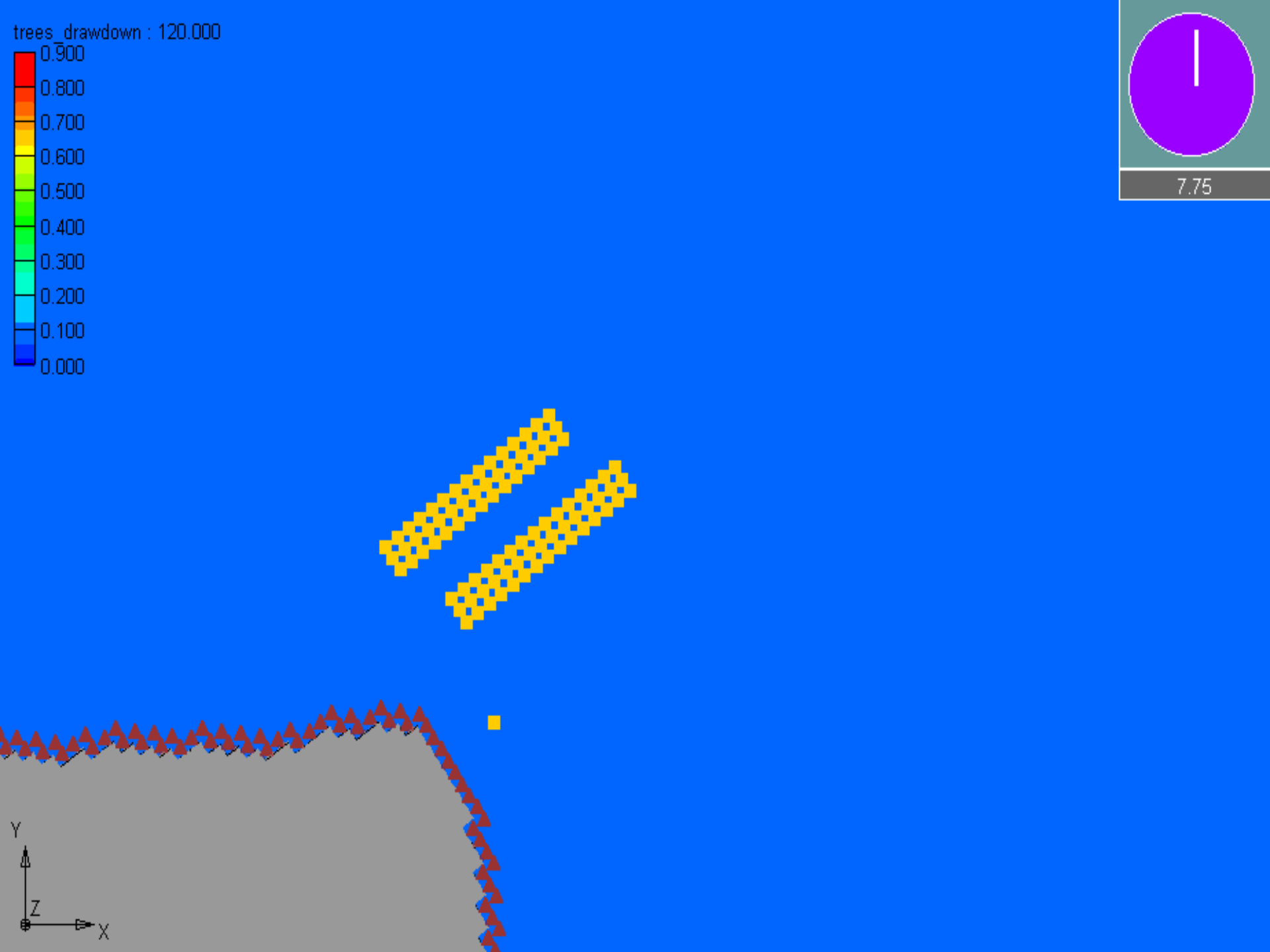
- 5-GALLON BUCKET TREES
  12 kg/day (mean)

- MATURE COTTONWOOD TREE
  1140 -1320 Kg/Day
  (300-350 gallons per day)

(J.M. Vose, U.S. Forest Service, written commun., 1997)

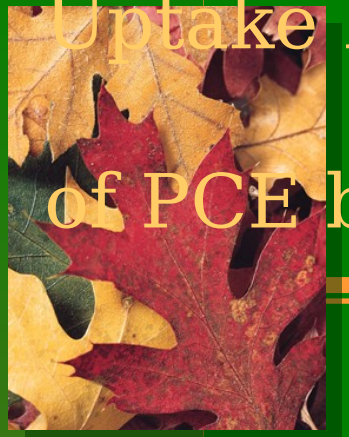
Hydraulic Control (Modeling Approach)

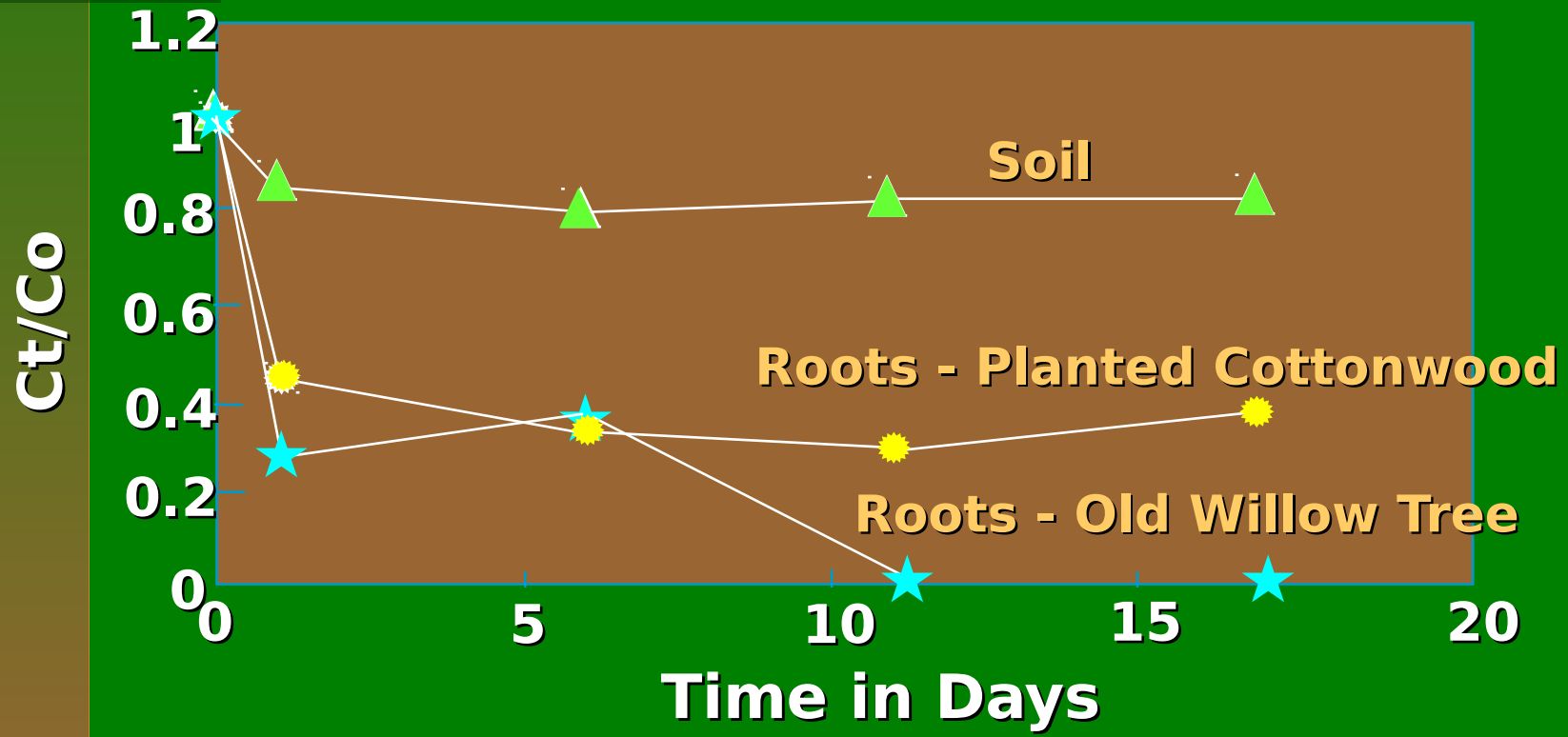
- Determine required amount of pumpage (Ground-water flow model - MODFLOW / MODMAN)
- Predict future transpiration at demonstration site (Hydrologic model - PROSPER)
- Determine timing of hydraulic control by planted trees (Combined results of MODFLOW and PROSPER)
- Compute mass flux changes attributable to trees


trees_drawdown : 120.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
7.75
Y
Z
X

Uptake Rate and Possible Transformation of PCE by Soils and Roots from the Site

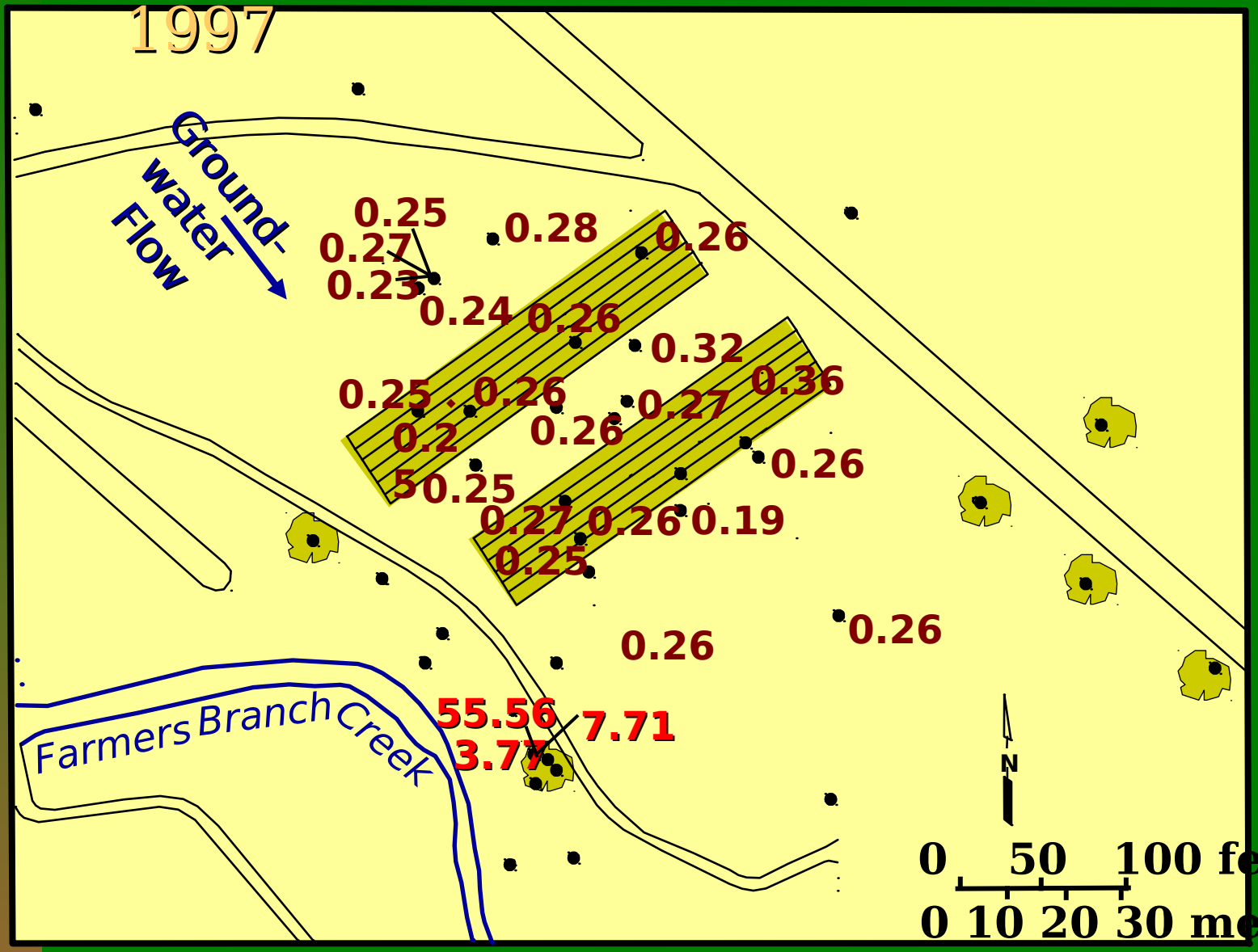
(Preliminary)



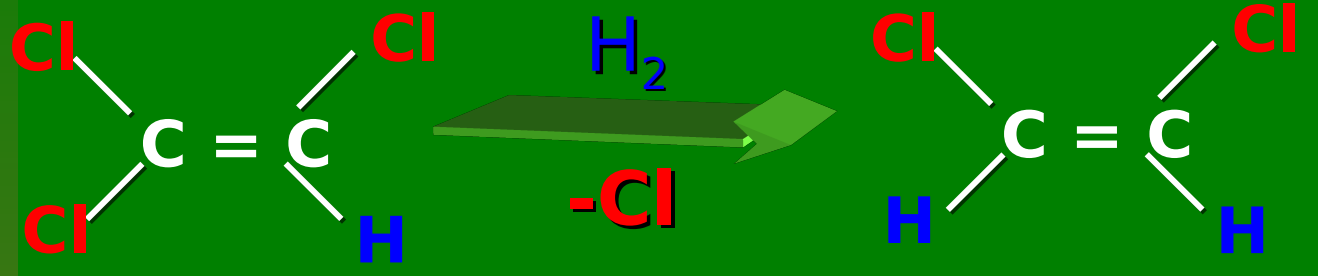


(Nzengung, Wolfe, and McCutcheon, USEPA, written commun., 19

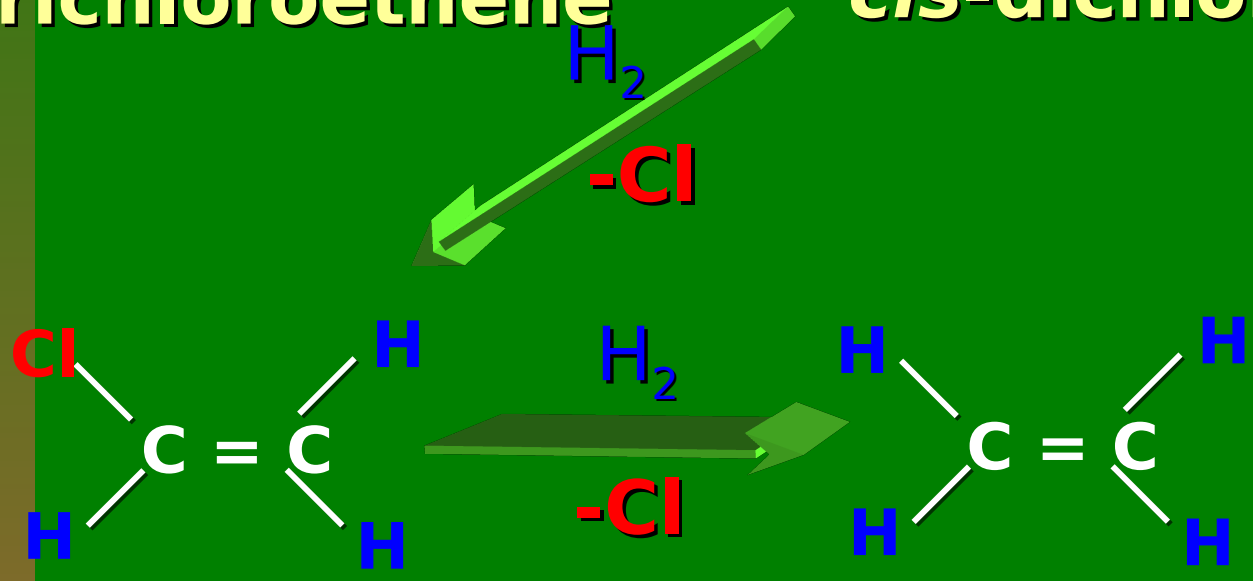
DCE / TCE in Ground Water, July 1997



Reductive Dechlorination of TCE



Trichloroethene ***cis*-dichloroethene**



Vinyl chloride **Ethene**

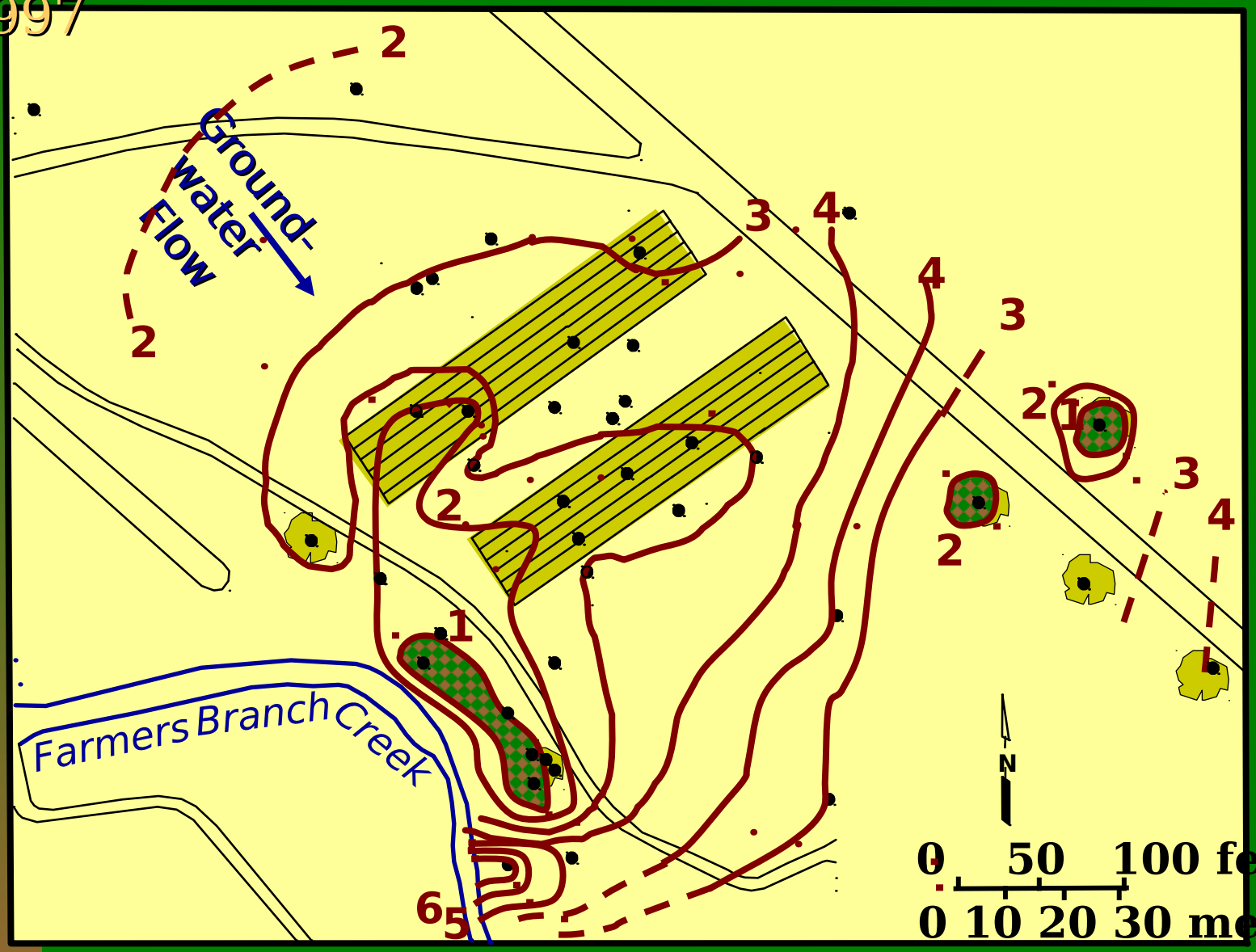
Ground-Water Chemistry Near Mature Tree(s)

- Mature Cottonwood vs. Planted Trees
  - **Higher Dissolved Organic Carbon**
  - **Lower Dissolved Oxygen**
  - **Higher Total Iron**
  - **Higher Molecular Hydrogen**
  - **25 % Greater Bicarbonate and pCO_2**
  - **80% Lower TCE**
  - **100 % Greater cis-1,2 DCE**

- Other Mature Trees

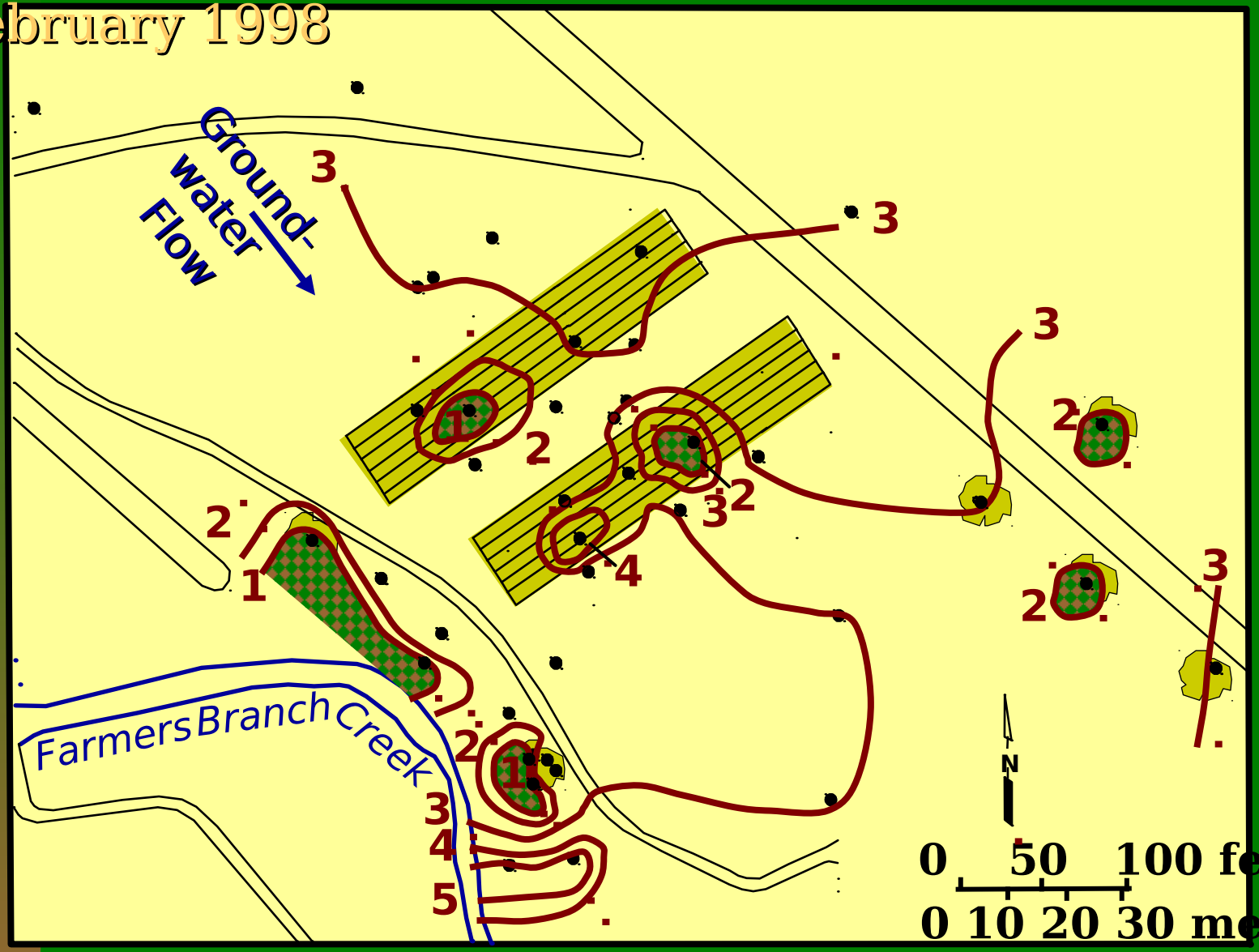
  Altered Redox Conditions and Changes in the cis-1,2 DCE and TCE Signatures

Distribution of Dissolved Oxygen (mg/L), November 1997

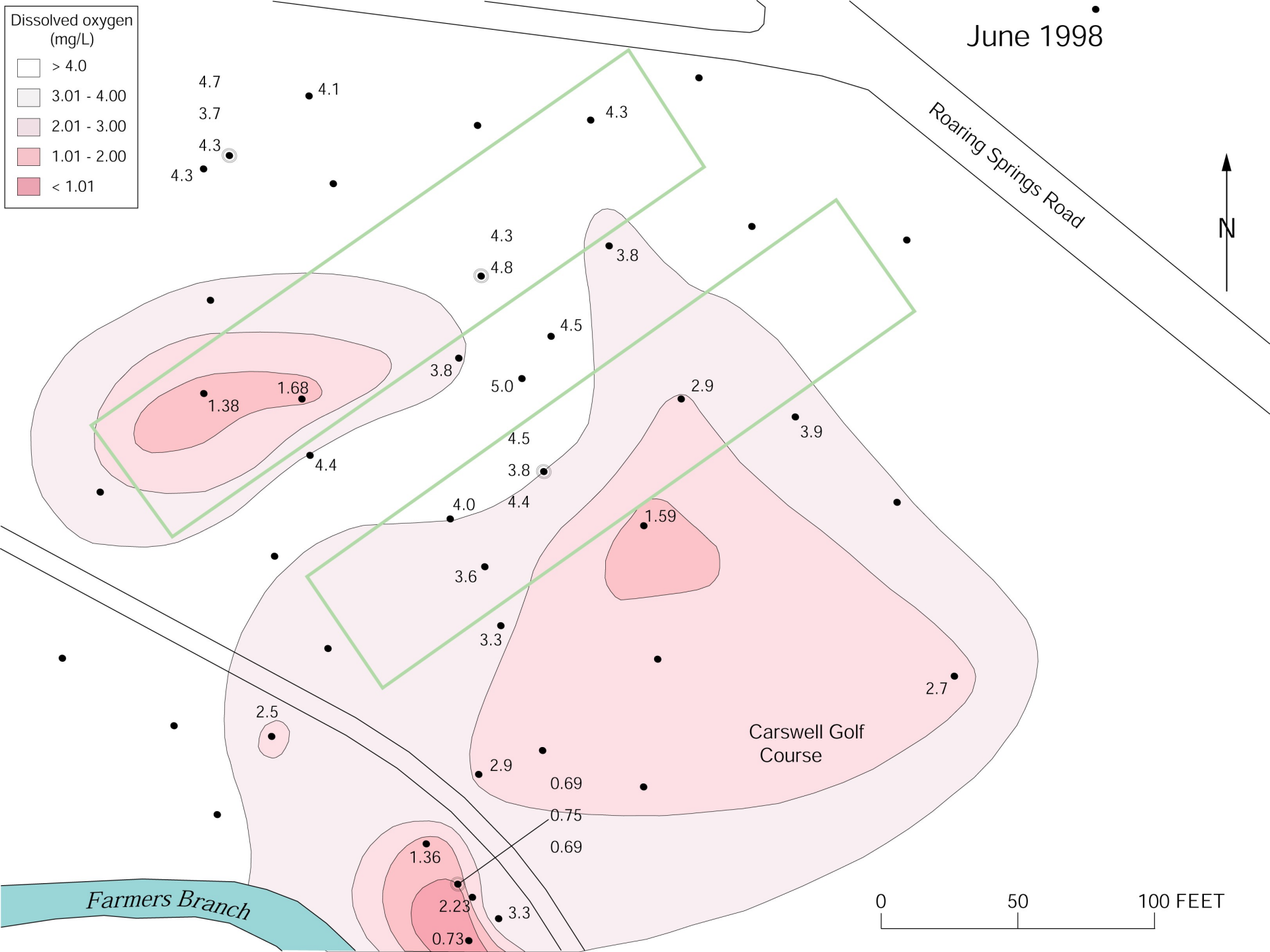


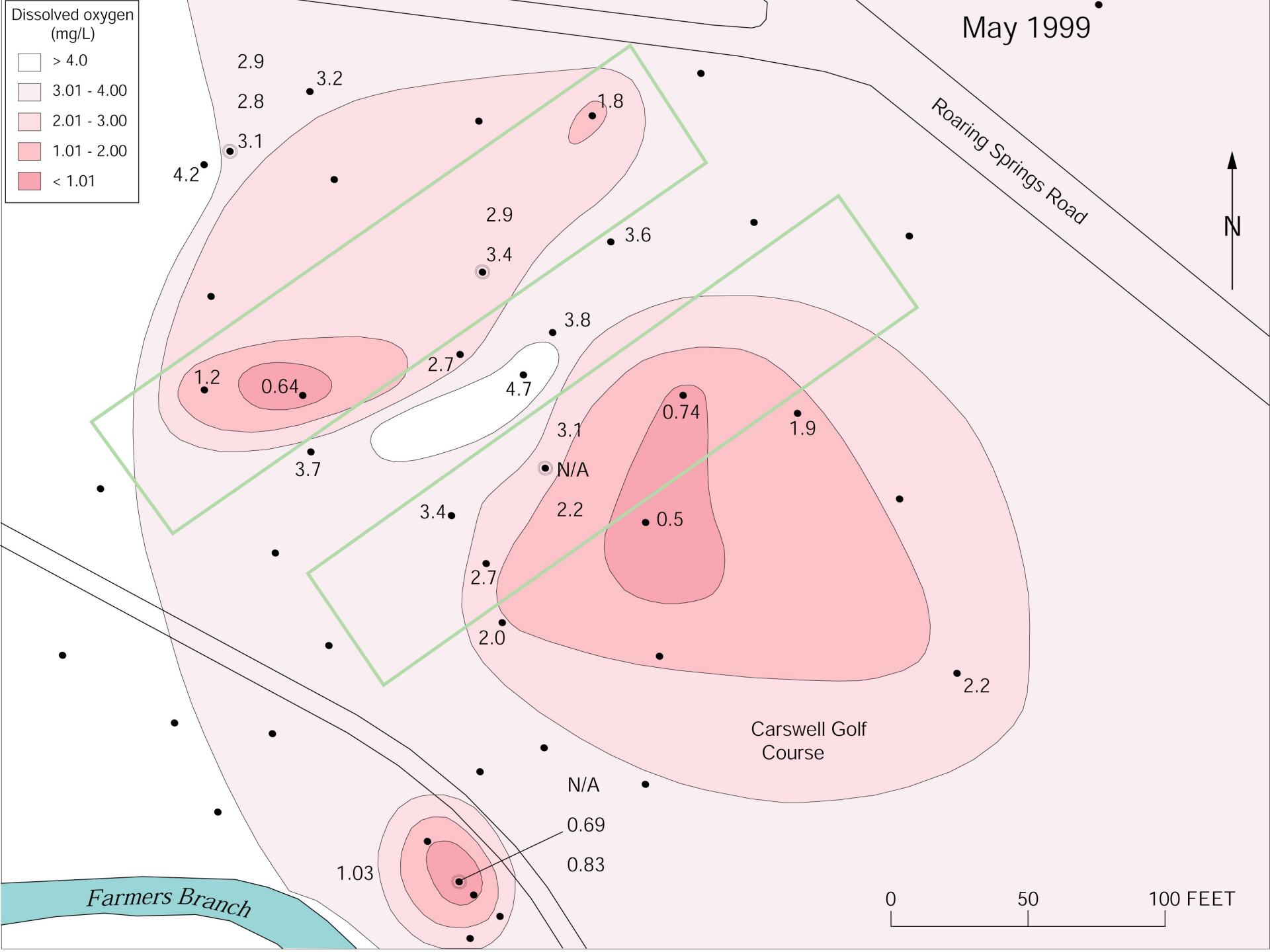
(Modified from R.W. Lee, USGS, written commun., 1998)

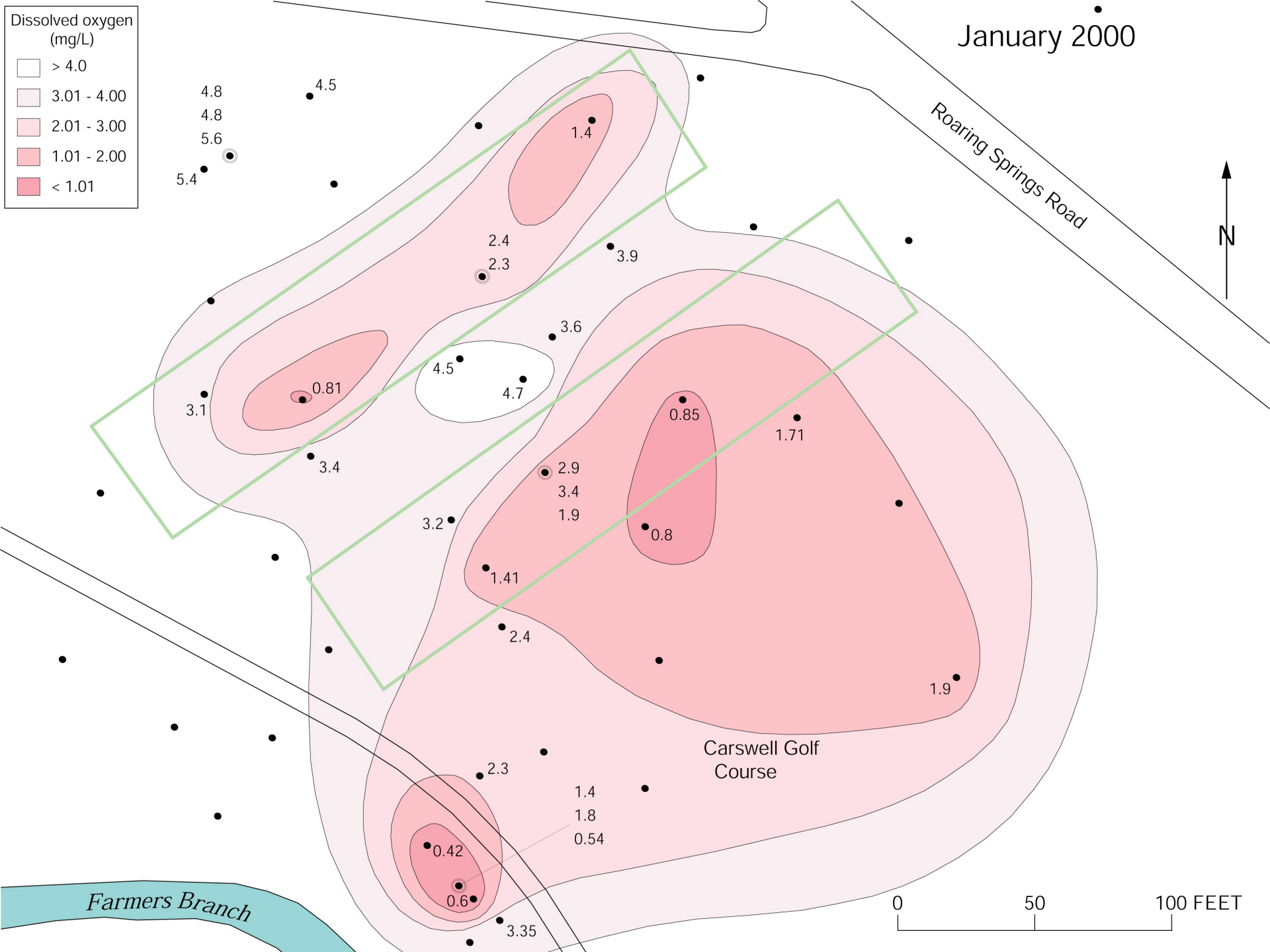
Distribution of Dissolved Oxygen (mg/L), February 1998

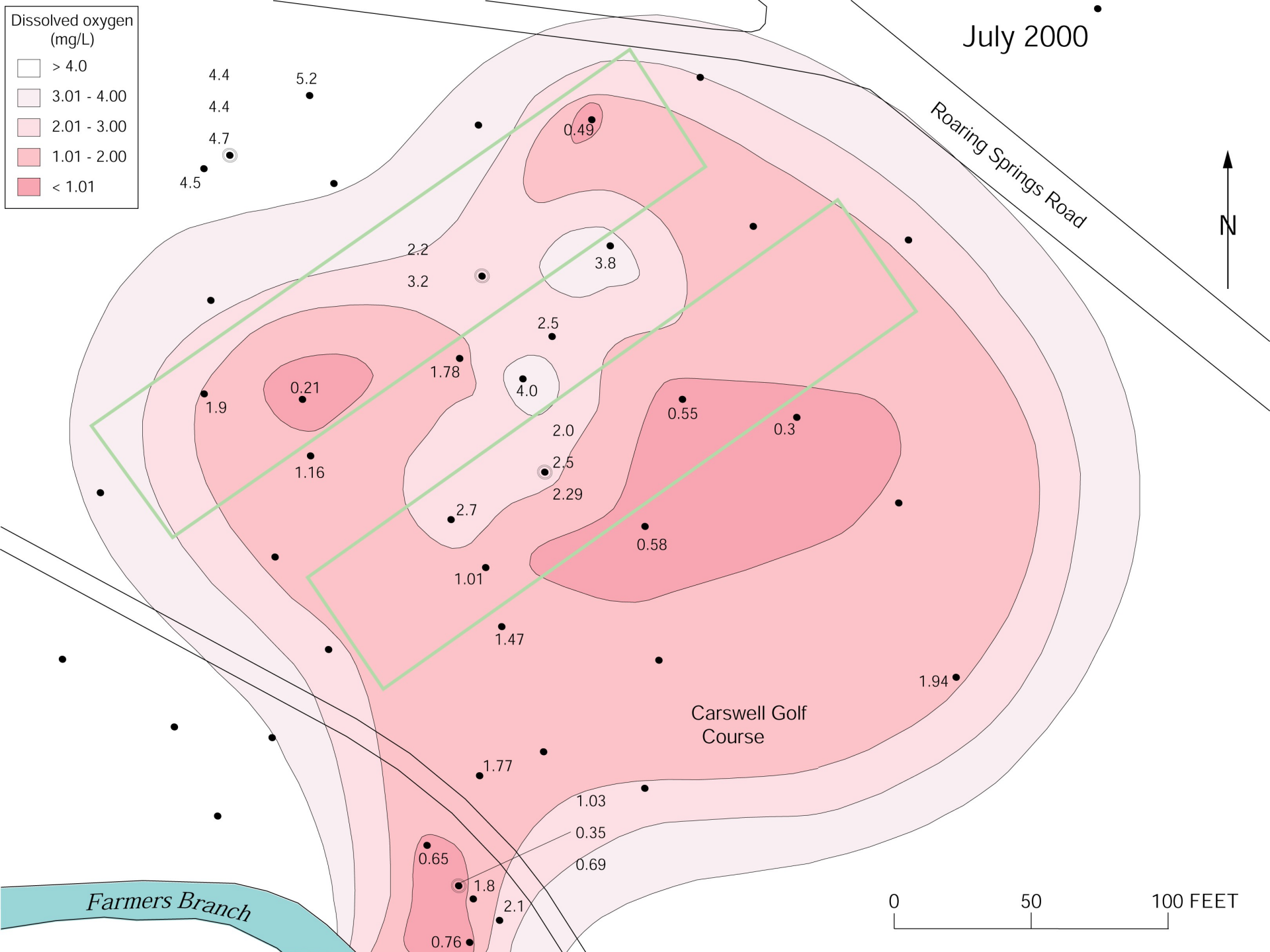


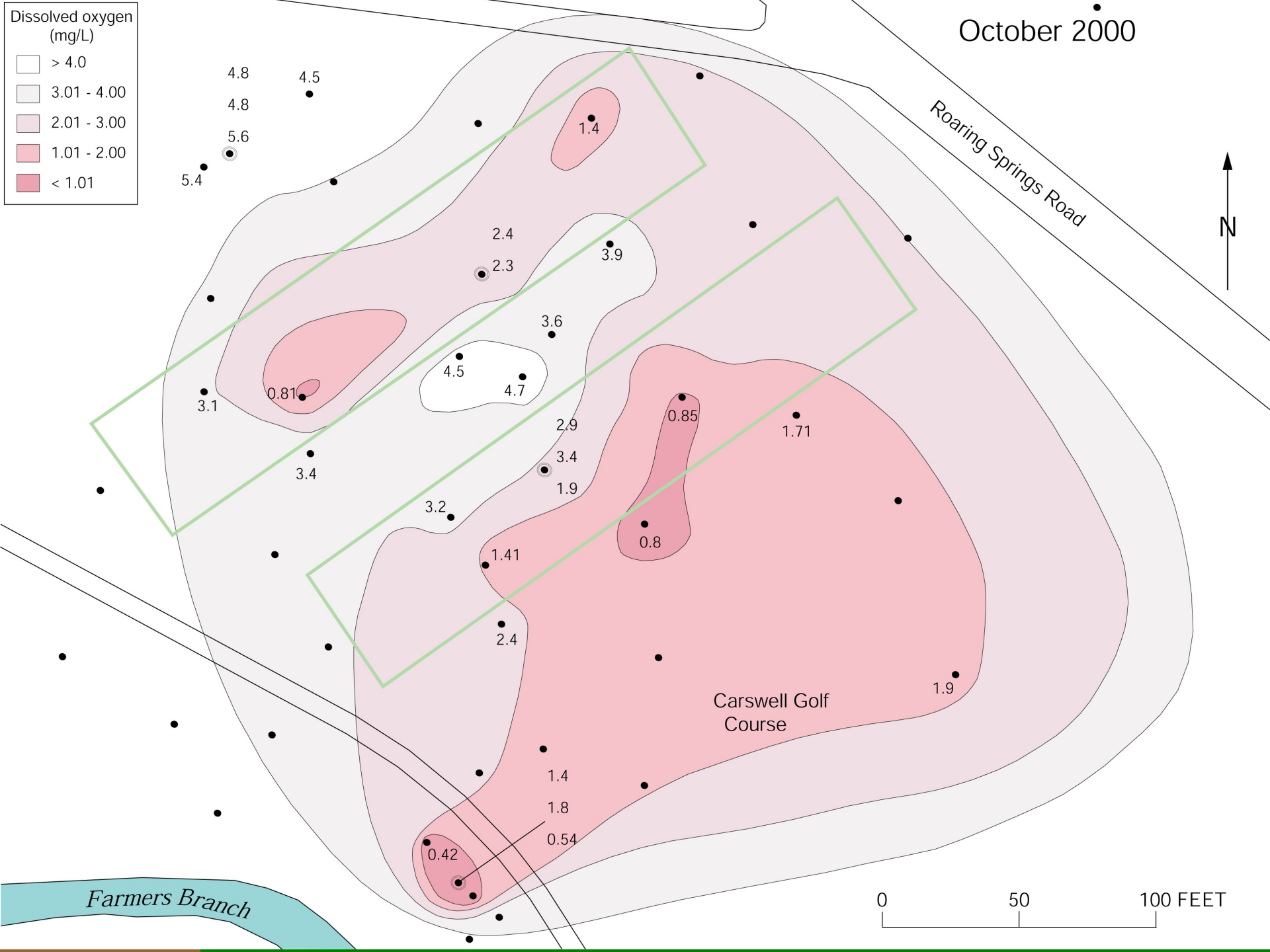
(R.W. Lee, USGS, written commun., 1998)

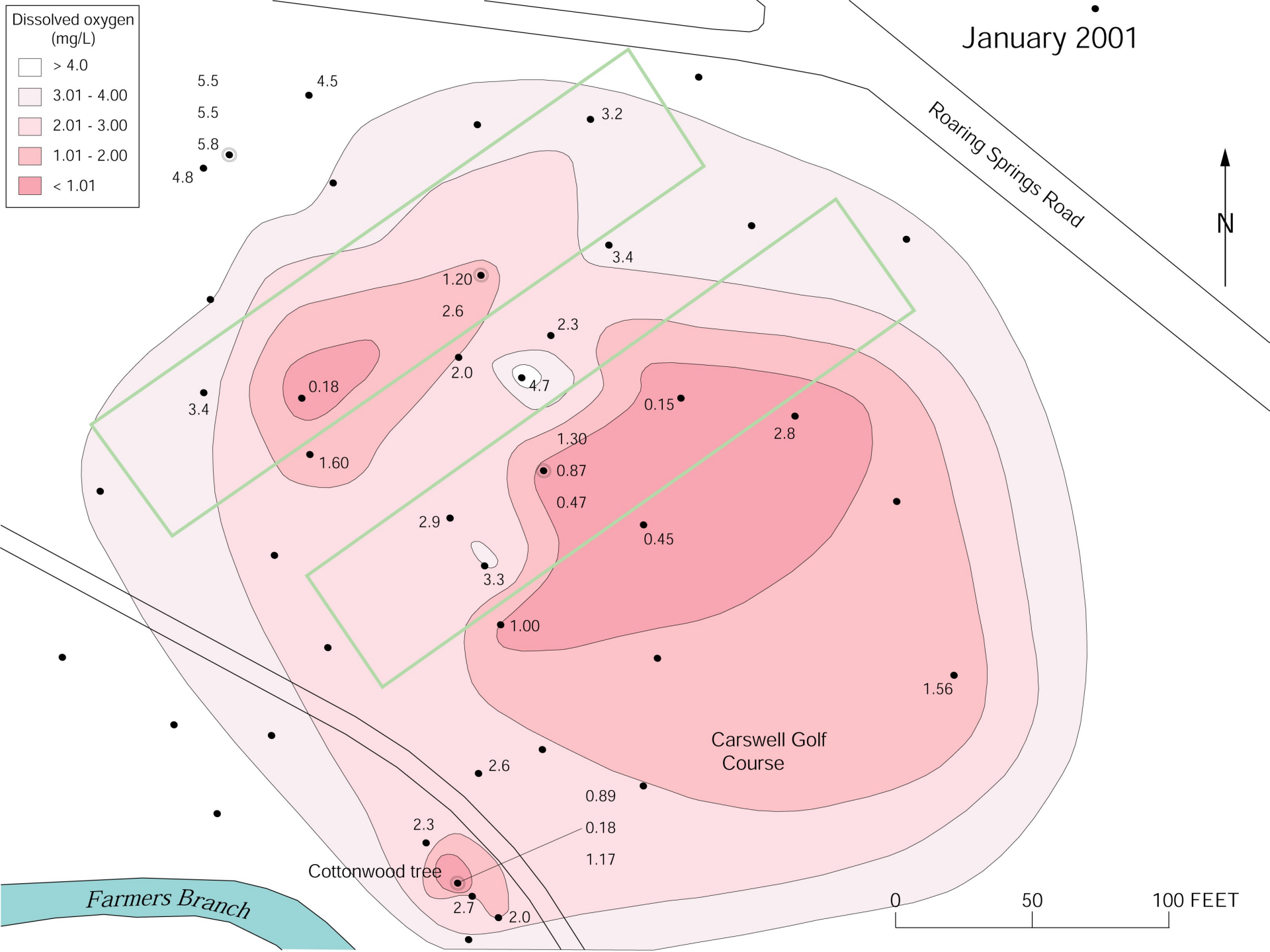

Dissolved oxygen (mg/L)
> 4.0
3.01 - 4.00
2.01 - 3.00
1.01 - 2.00
< 1.01
June 1998
Roaring Springs Road
N
Carswell Golf Course
Farmers Branch
0
50
100 FEET
4.7
4.1
3.7
4.3
4.3
4.3
4.3
4.8
3.8
4.5
3.8
1.68
1.38
5.0
2.9
3.9
4.5
4.4
3.8
4.0
4.4
1.59
3.6
3.3
2.7
2.5
2.9
0.69
0.75
0.69
1.36
2.23
3.3
0.73


Dissolved oxygen (mg/L)
> 4.0
3.01 - 4.00
2.01 - 3.00
1.01 - 2.00
< 1.01
May 1999
Roaring Springs Road
N
2.9
3.2
2.8
3.1
4.2
1.8
2.9
3.4
3.6
3.8
2.7
4.7
1.2
0.64
3.7
3.1
N/A
2.2
3.4
0.74
1.9
0.5
2.7
2.0
2.2
Carswell Golf Course
N/A
0.69
0.83
1.03
Farmers Branch
0
50
100 FEET

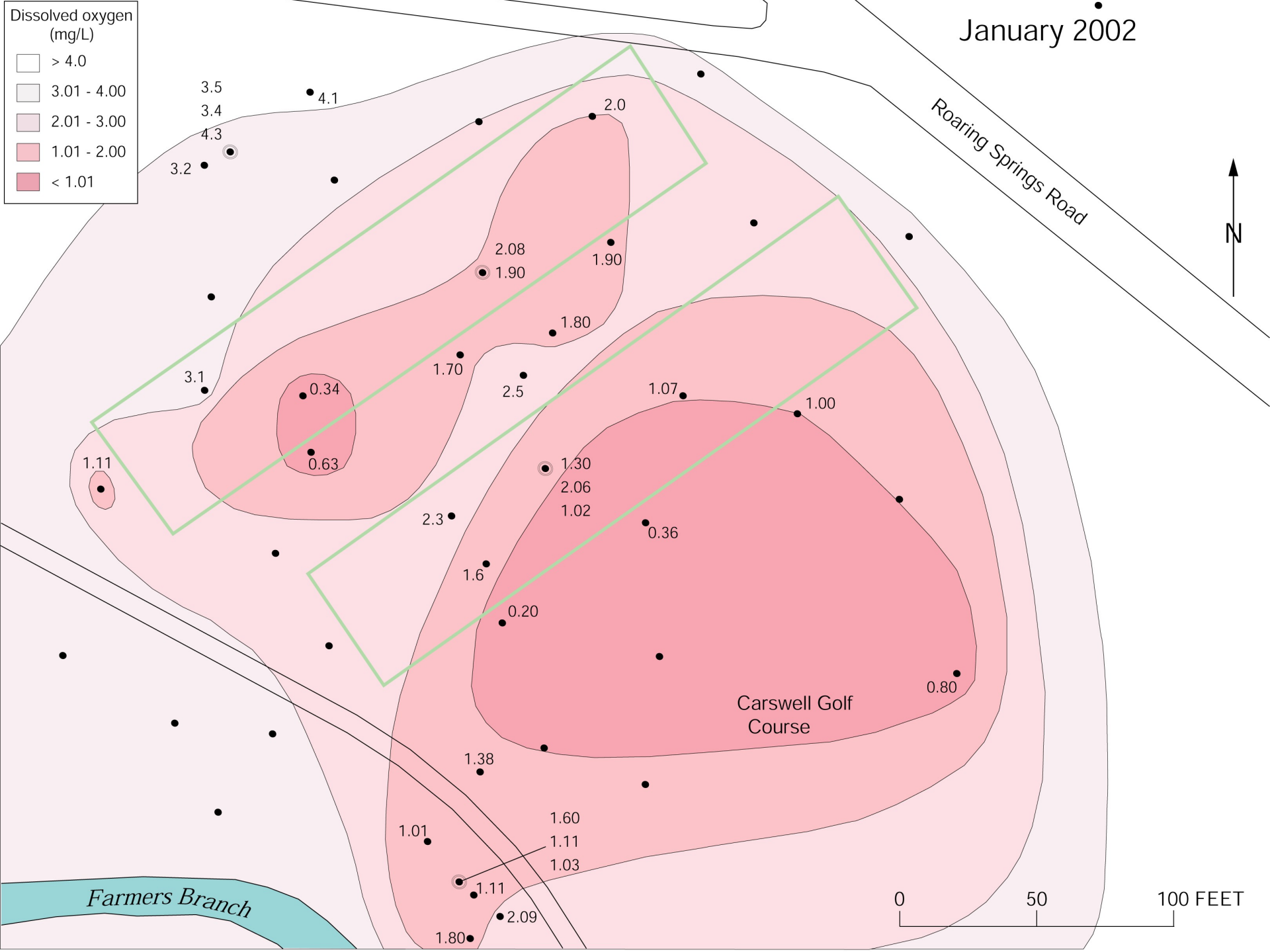

Dissolved oxygen (mg/L)
> 4.0
3.01 - 4.00
2.01 - 3.00
1.01 - 2.00
< 1.01
January 2000
Roaring Springs Road
N
4.8
4.8
5.6
5.4
4.5
1.4
2.4
2.3
3.9
3.6
4.5
4.7
0.81
3.1
3.4
0.85
1.71
2.9
3.4
1.9
3.2
0.8
1.41
2.4
1.9
Carswell Golf Course
2.3
1.4
1.8
0.54
0.42
0.6
3.35
Farmers Branch
0
50
100 FEET

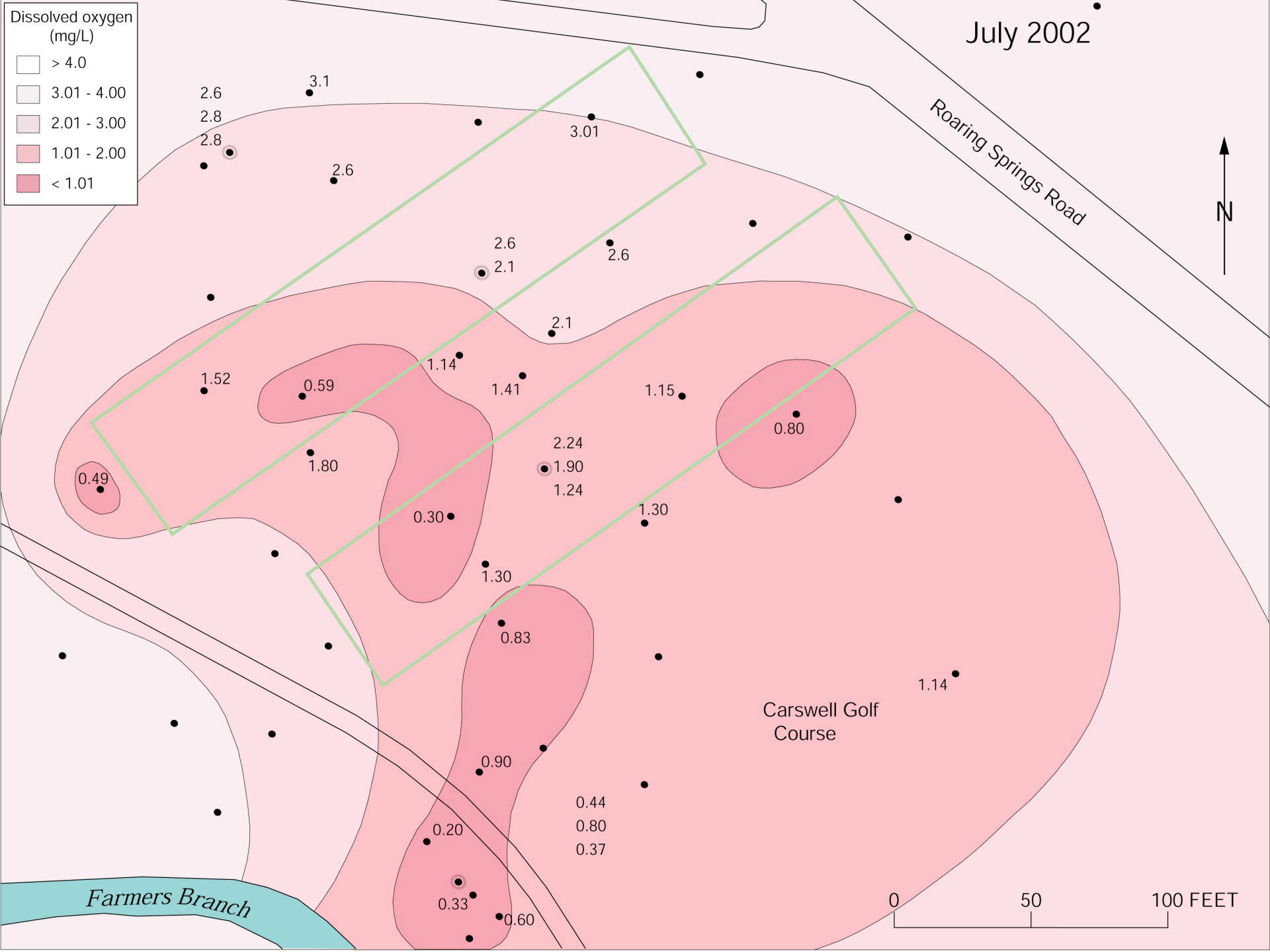

Dissolved oxygen (mg/L)
> 4.0
3.01 - 4.00
2.01 - 3.00
1.01 - 2.00
< 1.01
July 2000
Roaring Springs Road
N
Carswell Golf Course
Farmers Branch
0
50
100 FEET
4.4
4.4
4.7
4.5
5.2
0.49
2.2
3.2
3.8
2.5
1.78
4.0
0.21
1.9
1.16
2.0
2.5
2.29
2.7
0.55
0.3
0.58
1.01
1.47
1.94
1.77
1.03
0.35
0.69
0.65
1.8
2.1
0.76

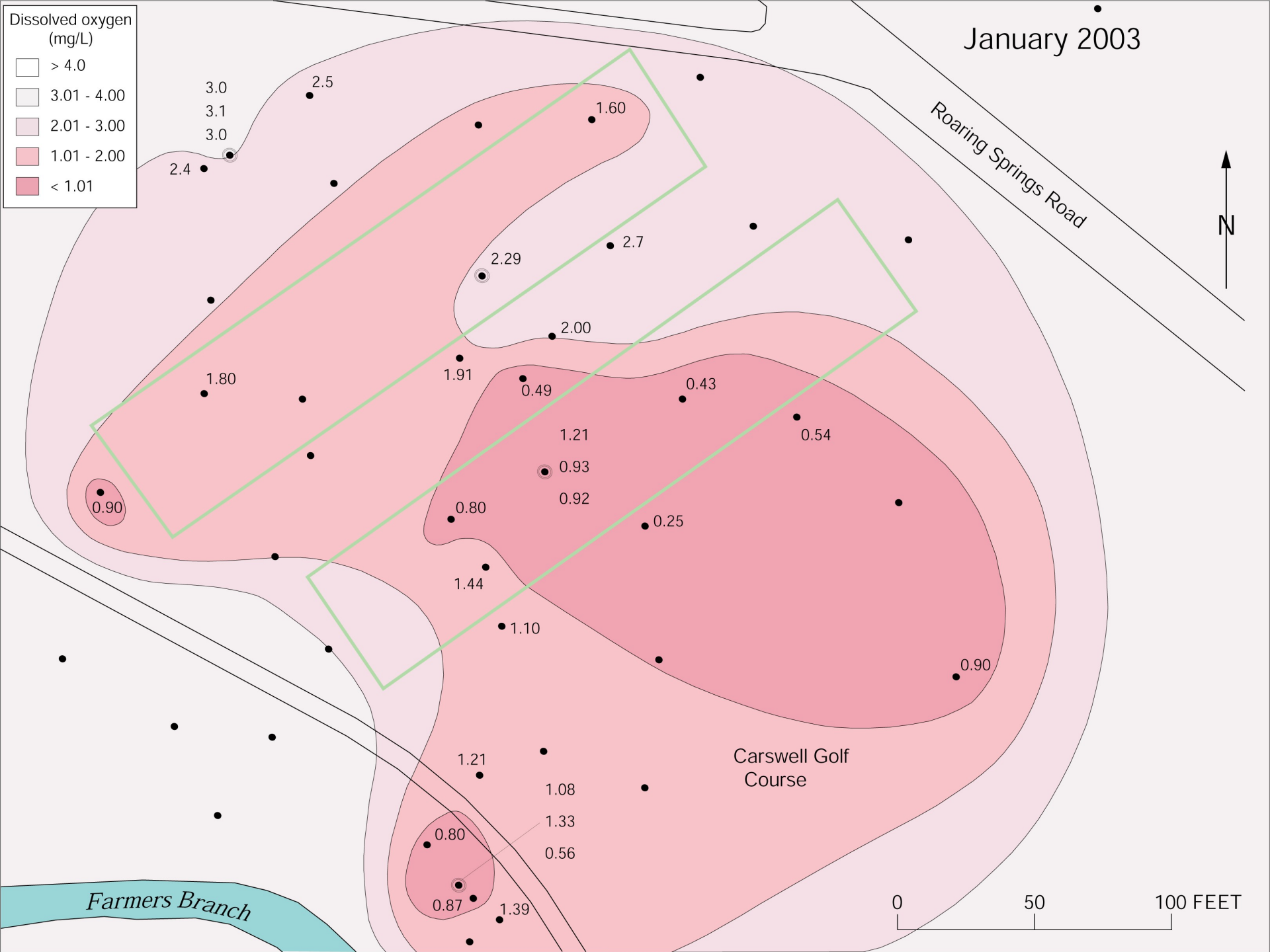

Dissolved oxygen (mg/L)
> 4.0
3.01 - 4.00
2.01 - 3.00
1.01 - 2.00
< 1.01
October 2000
Roaring Springs Road
N
Carswell Golf Course
Farmers Branch
0
50
100 FEET
4.8
4.5
4.8
5.6
5.4
1.4
2.4
2.3
3.9
3.6
4.5
4.7
0.81
3.1
3.4
2.9
3.4
1.9
3.2
0.85
1.71
0.8
1.41
2.4
1.9
1.4
1.8
0.54
0.42

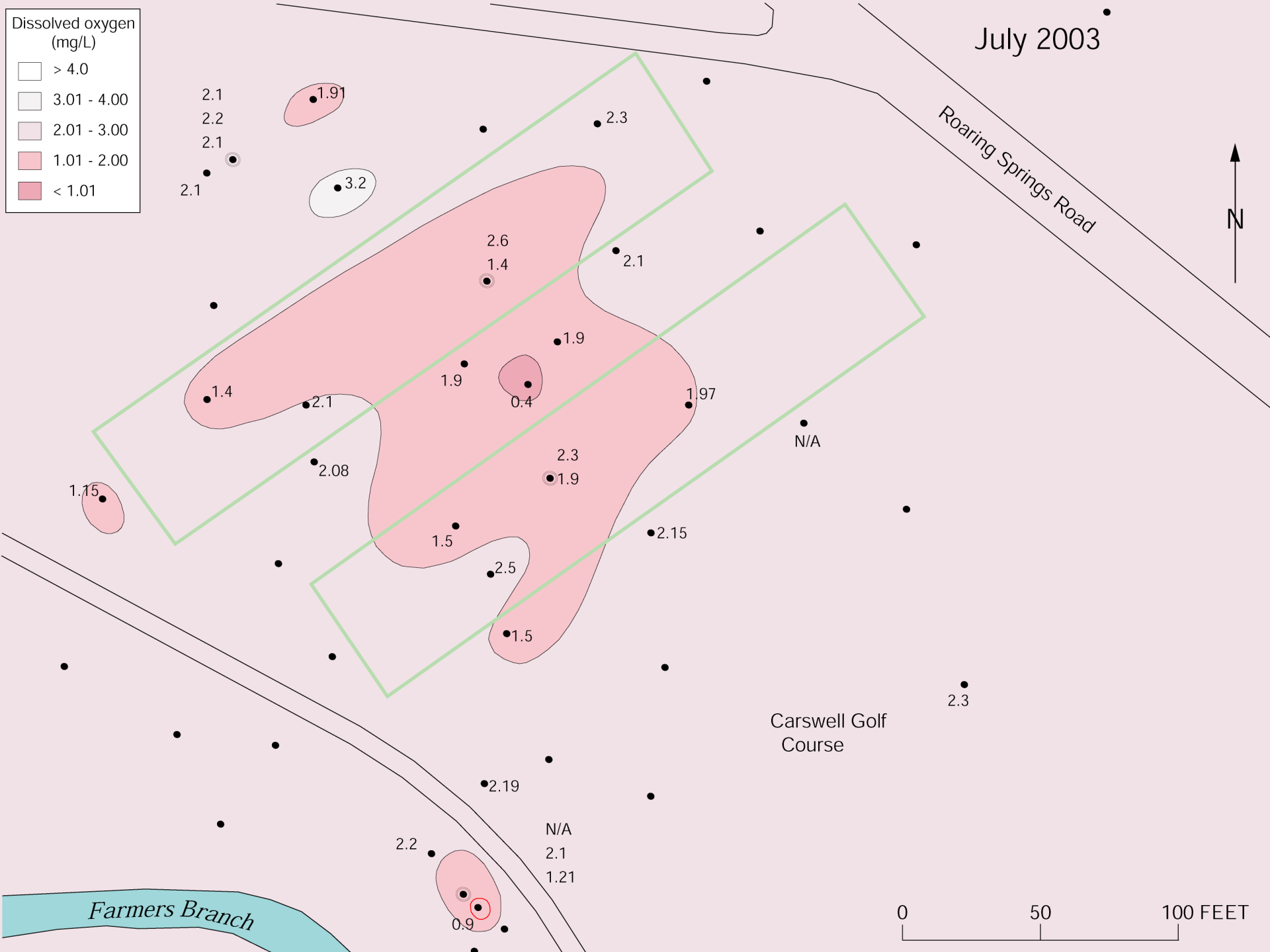

Dissolved oxygen (mg/L)
> 4.0
3.01 - 4.00
2.01 - 3.00
1.01 - 2.00
< 1.01
January 2001
Roaring Springs Road
N
5.5
4.5
5.5
5.8
4.8
3.2
3.4
1.20
2.6
2.3
2.0
0.18
4.7
3.4
0.15
2.8
1.30
1.60
0.87
0.47
2.9
0.45
3.3
1.00
1.56
Carswell Golf Course
2.6
0.89
2.3
0.18
1.17
Cottonwood tree
2.7
2.0
Farmers Branch
0
50
100 FEET

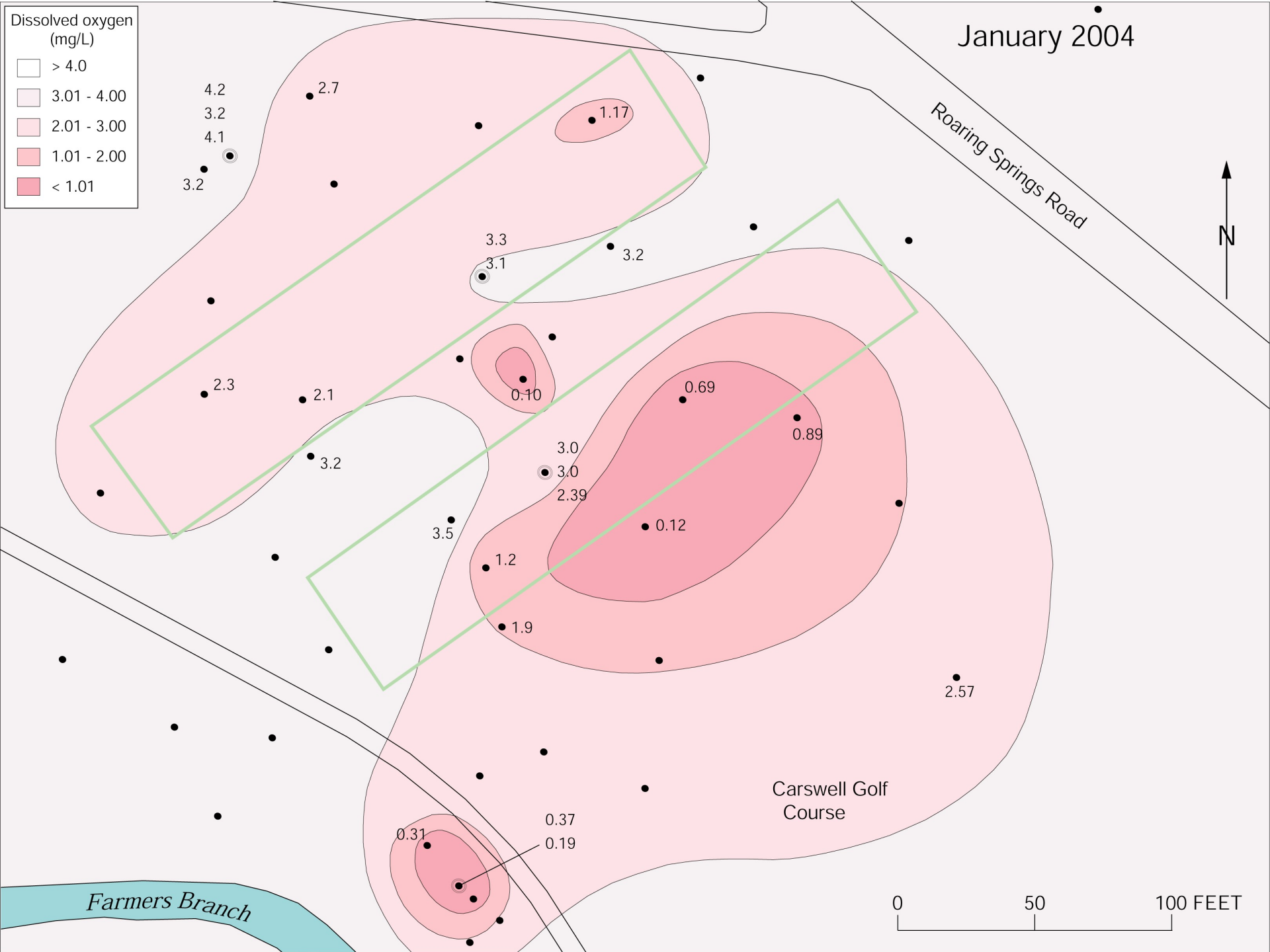
Dissolved oxygen (mg/L)
> 4.0
3.01 - 4.00
2.01 - 3.00
1.01 - 2.00
< 1.01
July 2001
Roaring Springs Road
N
3.1
3.3
3.3
2.8
2.8
3.3
1.50
1.80
2.8
3.1
1.80
0.53
1.10
3.1
1.44
1.28
0.10
2.13
0.40
1.20
1.99
1.60
0.29
2.0
1.72
1.92
Carswell Golf Course
N/A
0.85
1.04
0.20
Farmers Branch
0
50
100 FEET


Dissolved oxygen (mg/L)
> 4.0
3.01 - 4.00
2.01 - 3.00
1.01 - 2.00
< 1.01
January 2002
Roaring Springs Road
N
Carswell Golf Course
Farmers Branch
0
50
100 FEET
3.5
3.4
4.3
3.2
4.1
2.0
2.08
1.90
1.90
1.80
1.70
2.5
3.1
0.34
0.63
1.11
1.07
1.00
1.30
2.06
1.02
0.36
2.3
1.6
0.20
0.80
1.38
1.60
1.11
1.03
1.01
1.11
2.09
1.80

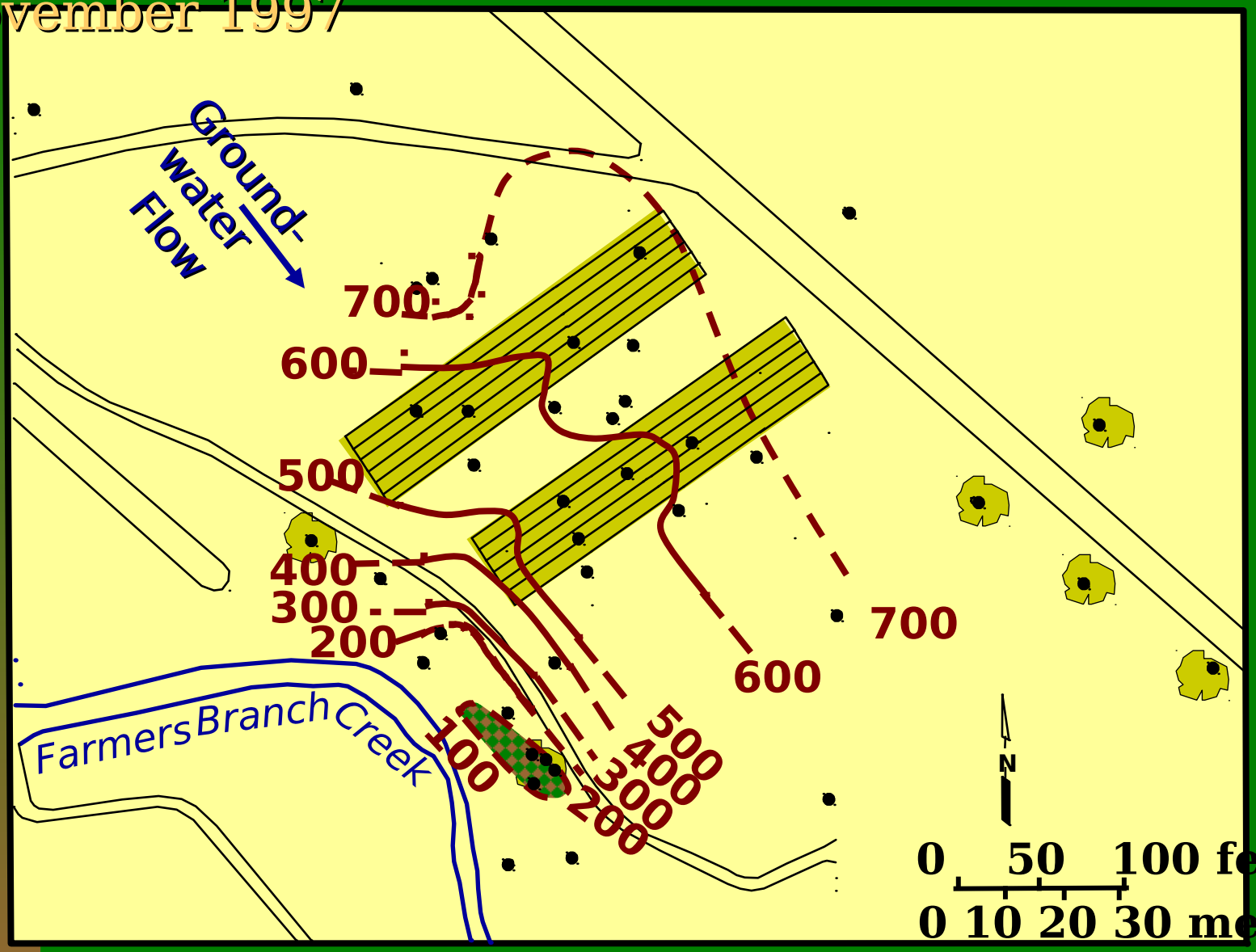

Dissolved oxygen (mg/L)
> 4.0
3.01 - 4.00
2.01 - 3.00
1.01 - 2.00
< 1.01
July 2002
Roaring Springs Road
N
2.6
2.8
2.8
3.1
3.01
2.6
2.6
2.1
2.6
2.1
1.52
0.59
1.14
1.41
1.15
0.80
0.49
1.80
2.24
1.90
1.24
0.30
1.30
1.30
0.83
1.14
Carswell Golf Course
0.90
0.44
0.80
0.37
0.20
Farmers Branch
0.33
0.60
0
50
100 FEET


Dissolved oxygen (mg/L)
> 4.0
3.01 - 4.00
2.01 - 3.00
1.01 - 2.00
< 1.01
January 2003
Roaring Springs Road
N
3.0
3.1
3.0
2.4
2.5
1.60
2.7
2.29
2.00
1.80
1.91
0.49
0.43
0.54
1.21
0.93
0.92
0.90
0.80
0.25
1.44
1.10
0.90
Carswell Golf Course
1.21
1.08
1.33
0.56
0.80
0.87
1.39
Farmers Branch
0
50
100 FEET

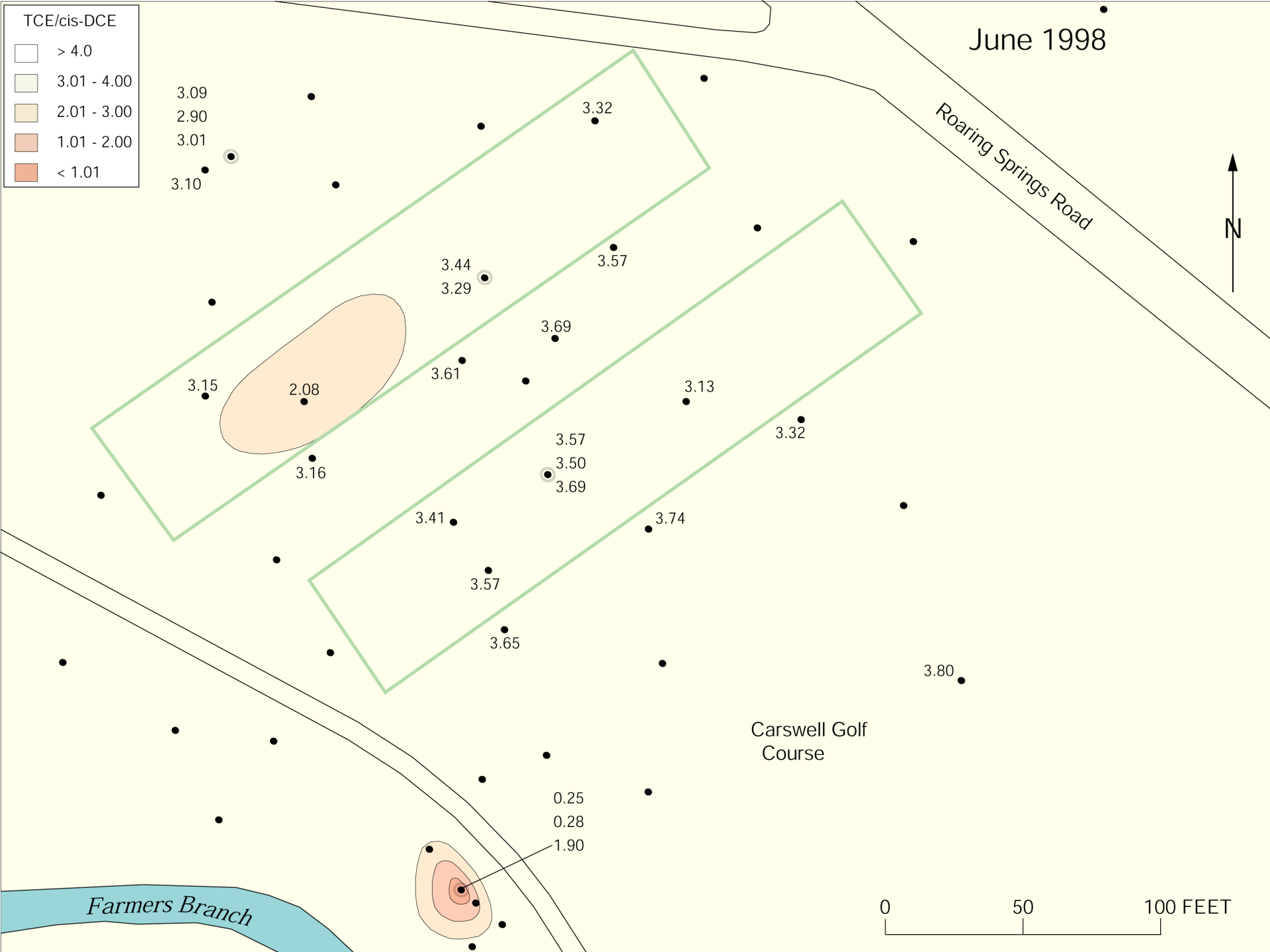

Dissolved oxygen (mg/L)
> 4.0
3.01 - 4.00
2.01 - 3.00
1.01 - 2.00
< 1.01
July 2003
Roaring Springs Road
N
2.1
2.2
2.1
2.1
1.91
2.3
3.2
2.6
1.4
2.1
1.9
1.9
1.4
2.1
0.4
1.97
N/A
2.3
2.08
1.9
1.15
1.5
2.15
2.5
1.5
2.3
Carswell Golf Course
2.19
N/A
2.1
1.21
2.2
0.9
Farmers Branch
0
50
100 FEET

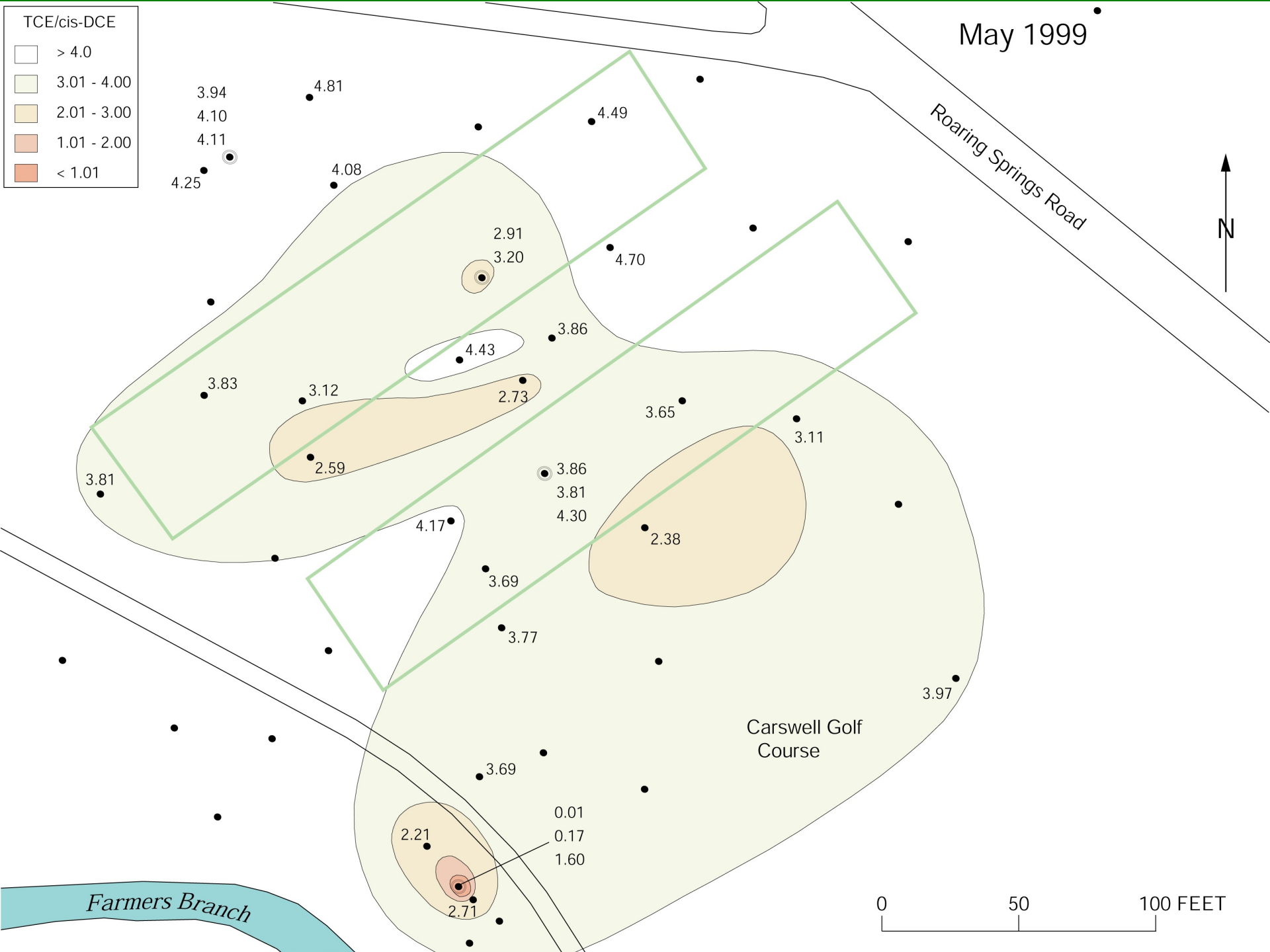

Dissolved oxygen (mg/L)
> 4.0
3.01 - 4.00
2.01 - 3.00
1.01 - 2.00
< 1.01
January 2004
Roaring Springs Road
N
4.2
3.2
4.1
3.2
2.7
1.17
3.3
3.1
3.2
2.3
2.1
0.10
0.69
0.89
3.0
3.0
2.39
3.2
3.5
0.12
1.2
1.9
2.57
Carswell Golf Course
0.37
0.19
0.31
Farmers Branch
0
50
100 FEET

Distribution of TCE (μg/L) in Ground Water, November 1997



(R.W. Lee, USGS, written commun., 1998)


TCE/cis-DCE
> 4.0
3.01 - 4.00
2.01 - 3.00
1.01 - 2.00
< 1.01
June 1998
Roaring Springs Road
N
3.09
2.90
3.01
3.10
3.32
3.44
3.29
3.57
3.69
3.61
3.15
2.08
3.13
3.32
3.57
3.50
3.69
3.16
3.41
3.74
3.57
3.65
3.80
Carswell Golf Course
0.25
0.28
1.90
Farmers Branch
0
50
100 FEET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2.01 - 3.00
1.01 - 2.00
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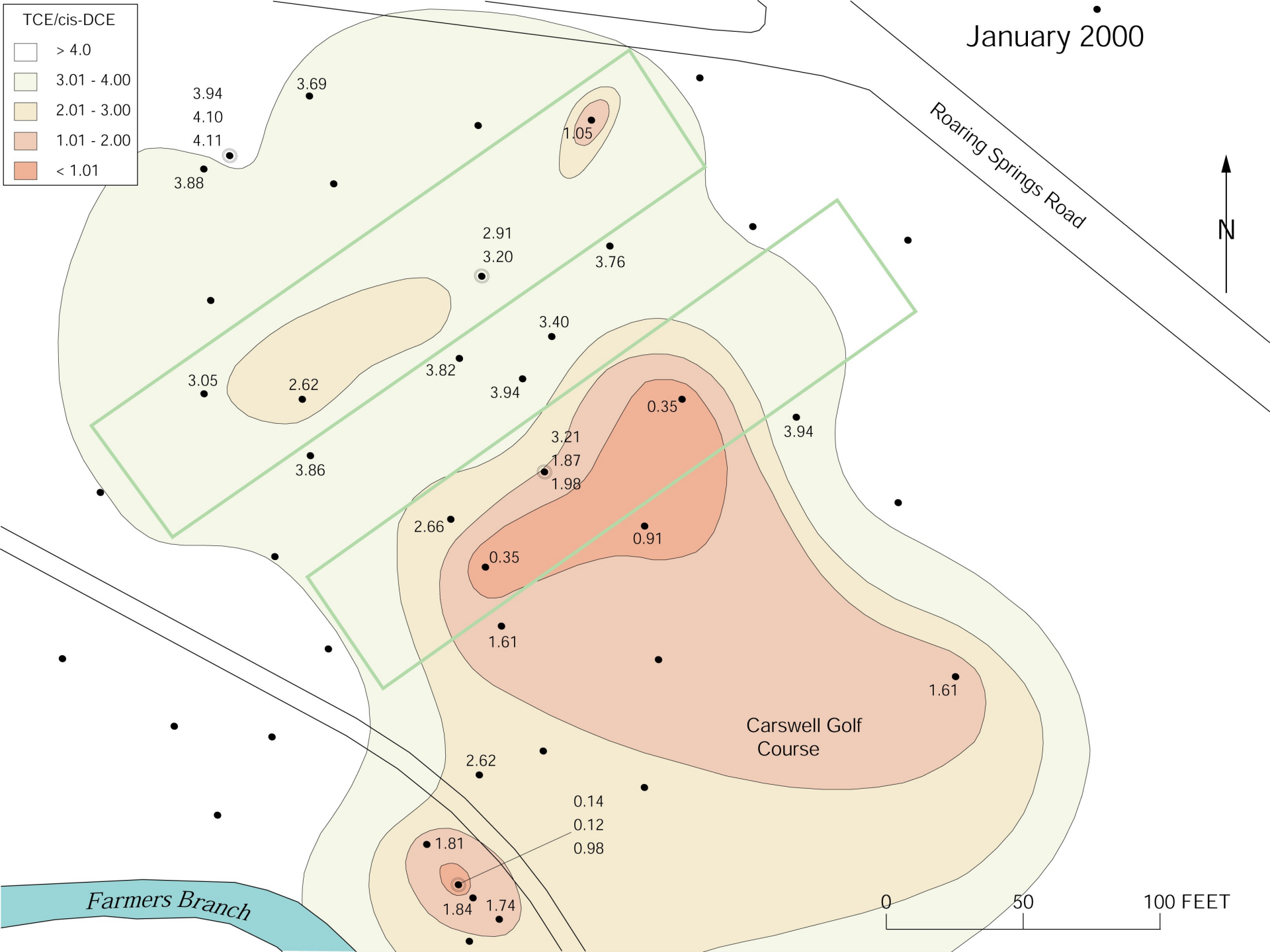
May 1999
Roaring Springs Road
N
3.94
4.10
4.11
4.25
4.81
4.08
4.49
2.91
3.20
4.70
3.86
4.43
3.83
3.12
2.73
3.65
3.11
2.59
3.81
3.86
3.81
4.30
4.17
2.38
3.69
3.77
3.97
Carswell Golf Course
3.69
0.01
0.17
1.60
2.21
2.71
Farmers Branch
0
50
100 FEET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January 2000
Roaring Springs Road
N
3.94
4.10
4.11
3.88
3.69
1.05
2.91
3.20
3.76
3.40
3.05
2.62
3.82
3.94
3.86
0.35
3.21
1.87
1.98
3.94
2.66
0.91
0.35
1.61
1.61
Carswell Golf Course
2.62
0.14
0.12
0.98
1.81
1.84
1.74
Farmers Branch
0
50
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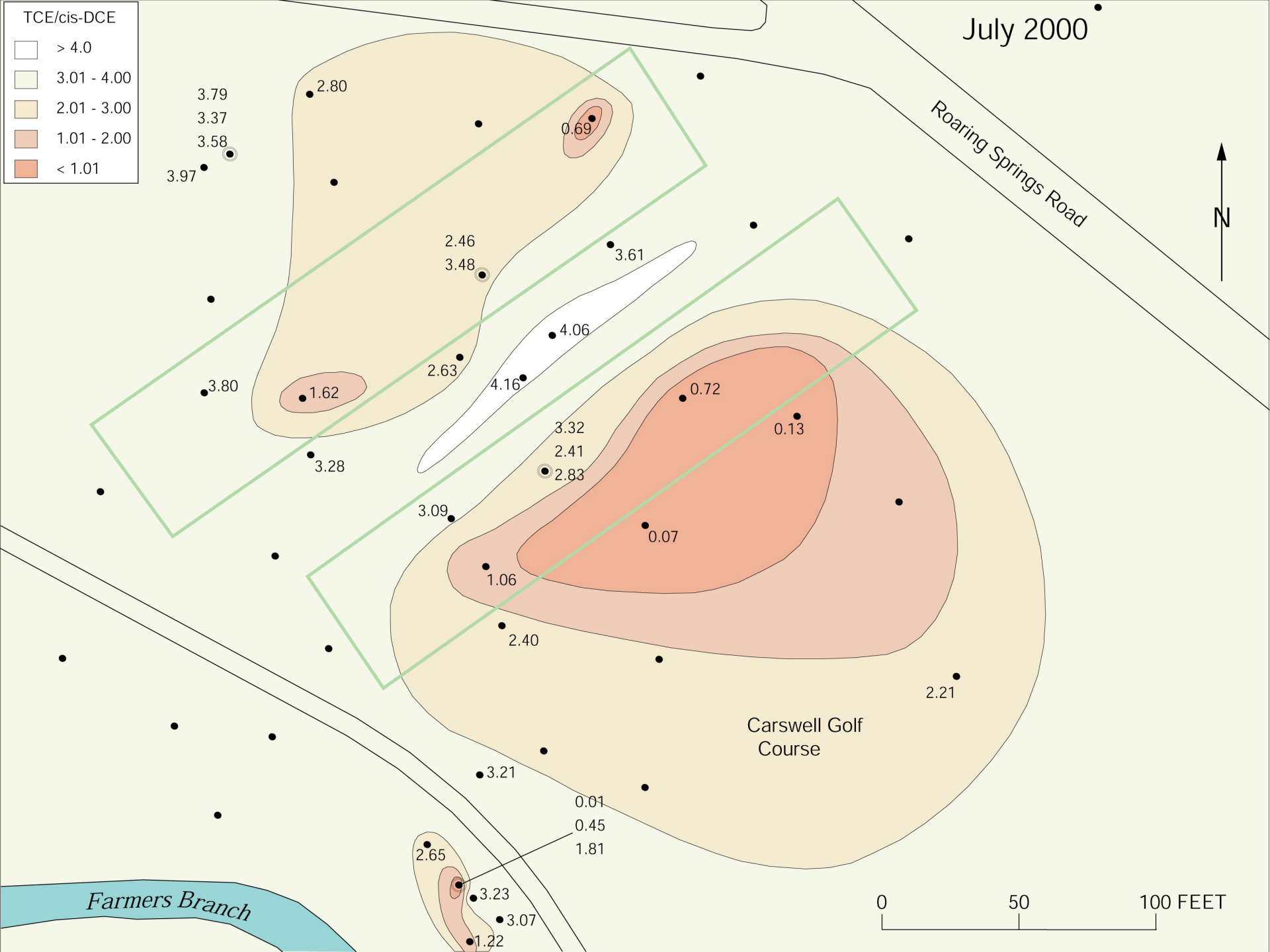
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1.01 - 2.00
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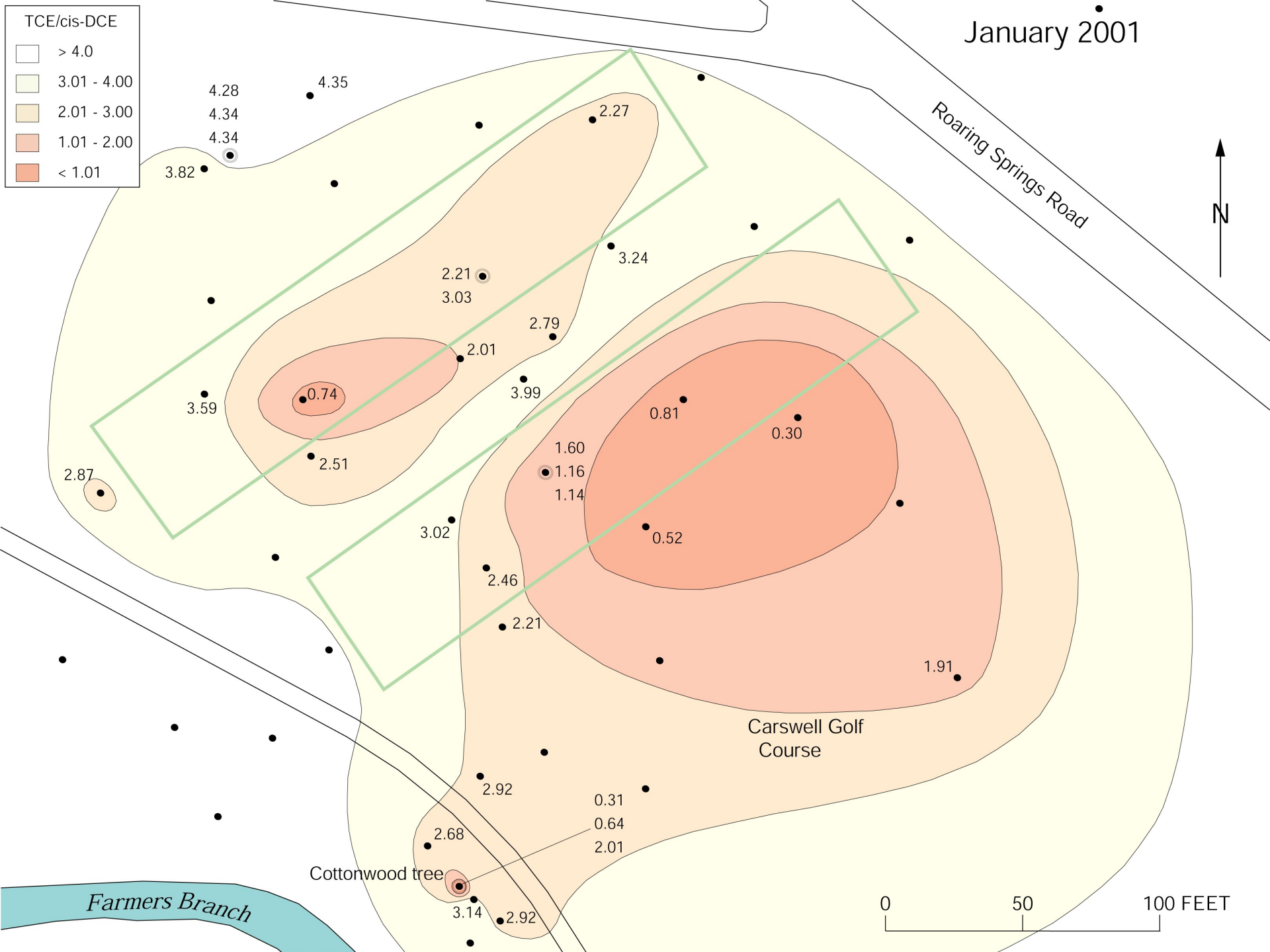
July 2000
Roaring Springs Road
N
Carswell Golf Course
Farmers Branch
0
50
100 FEET
3.79
3.37
3.58
3.97
2.80
0.69
2.46
3.48
3.61
4.06
2.63
4.16
3.80
1.62
3.28
0.72
0.13
3.32
2.41
2.83
3.09
0.07
1.06
2.40
2.21
3.21
0.01
0.45
1.81
2.65
3.23
3.07
1.22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2.01 - 3.00
1.01 - 2.00
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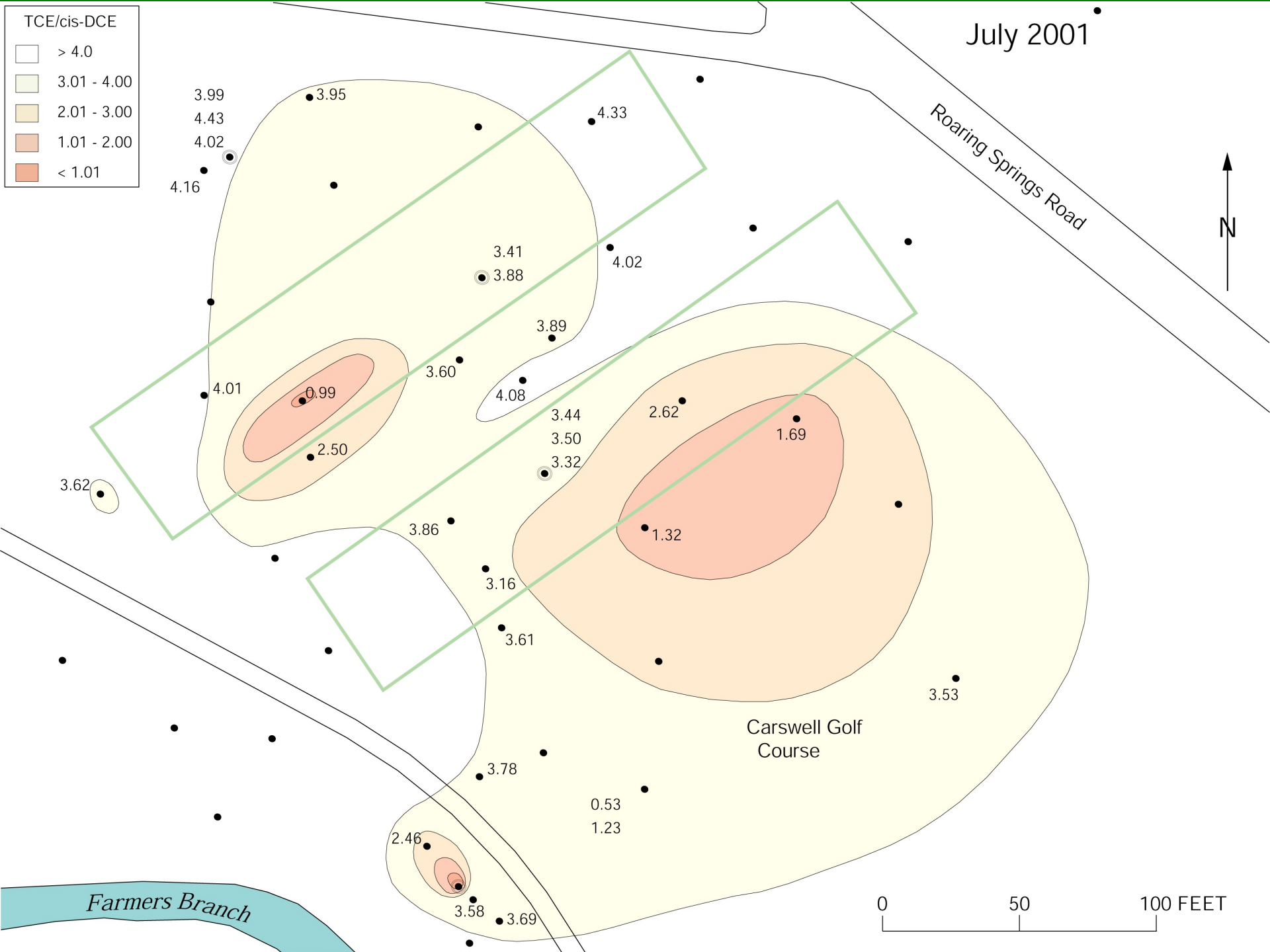
January 2001
Roaring Springs Road
N
4.28
4.34
4.34
4.35
3.82
2.27
3.24
2.21
3.03
2.79
2.01
3.99
3.59
0.74
2.51
2.87
0.81
0.30
1.60
1.16
1.14
0.52
3.02
2.46
2.21
1.91
Carswell Golf Course
2.92
0.31
0.64
2.01
2.68
Cottonwood tree
3.14
2.92
Farmers Branch
0
50
100 FEET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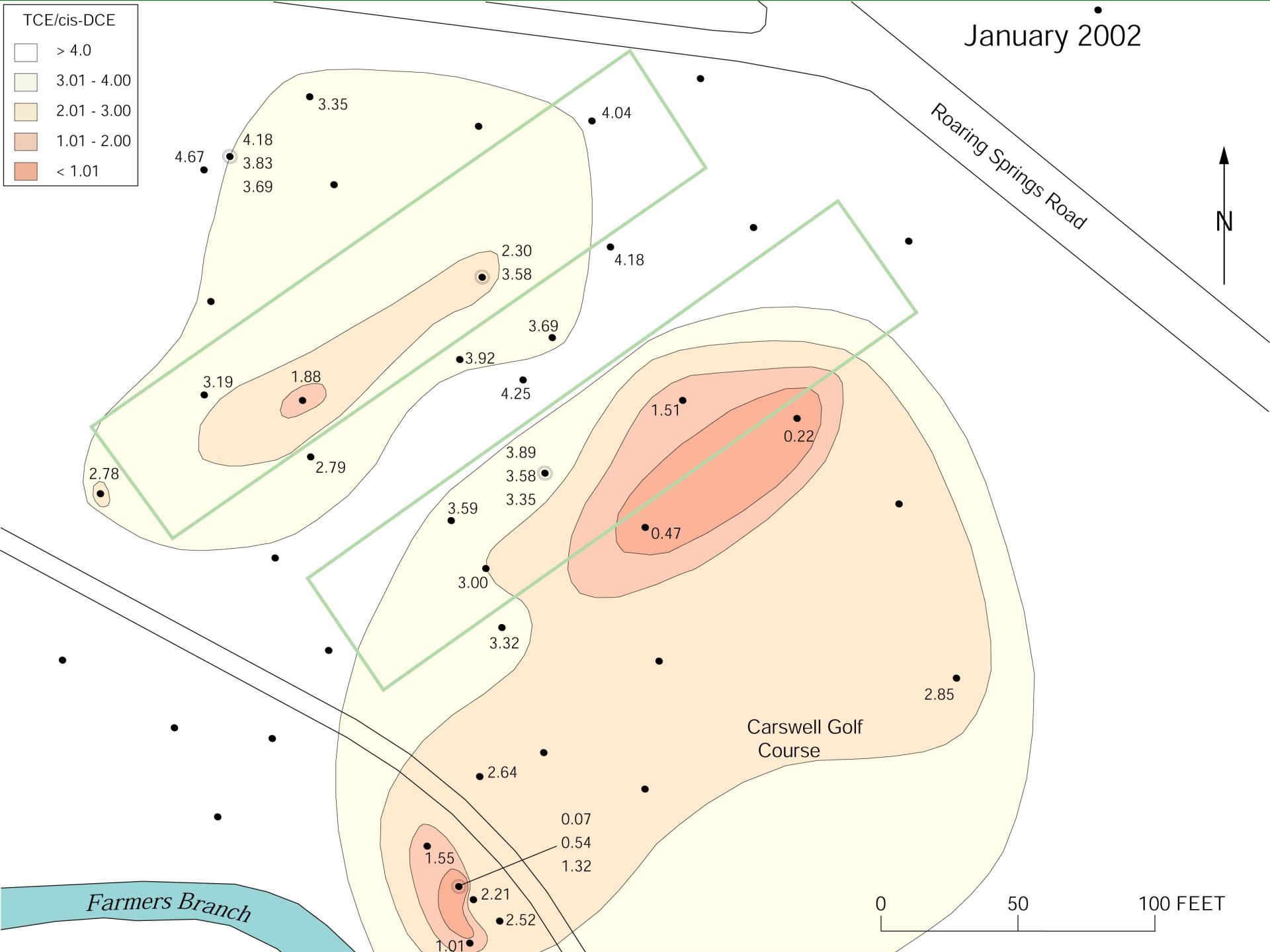
2.01 - 3.00
1.01 - 2.00
< 1.01
July 2001
Roaring Springs Road
N
3.99
4.43
4.02
4.16
3.95
4.33
3.41
3.88
4.02
3.89
3.60
4.08
4.01
0.99
2.50
3.62
3.44
3.50
3.32
2.62
1.69
1.32
3.86
3.16
3.61
3.53
Carswell Golf Course
3.78
0.53
1.23
2.46
3.58
3.69
Farmers Branch
0
50
100 FEET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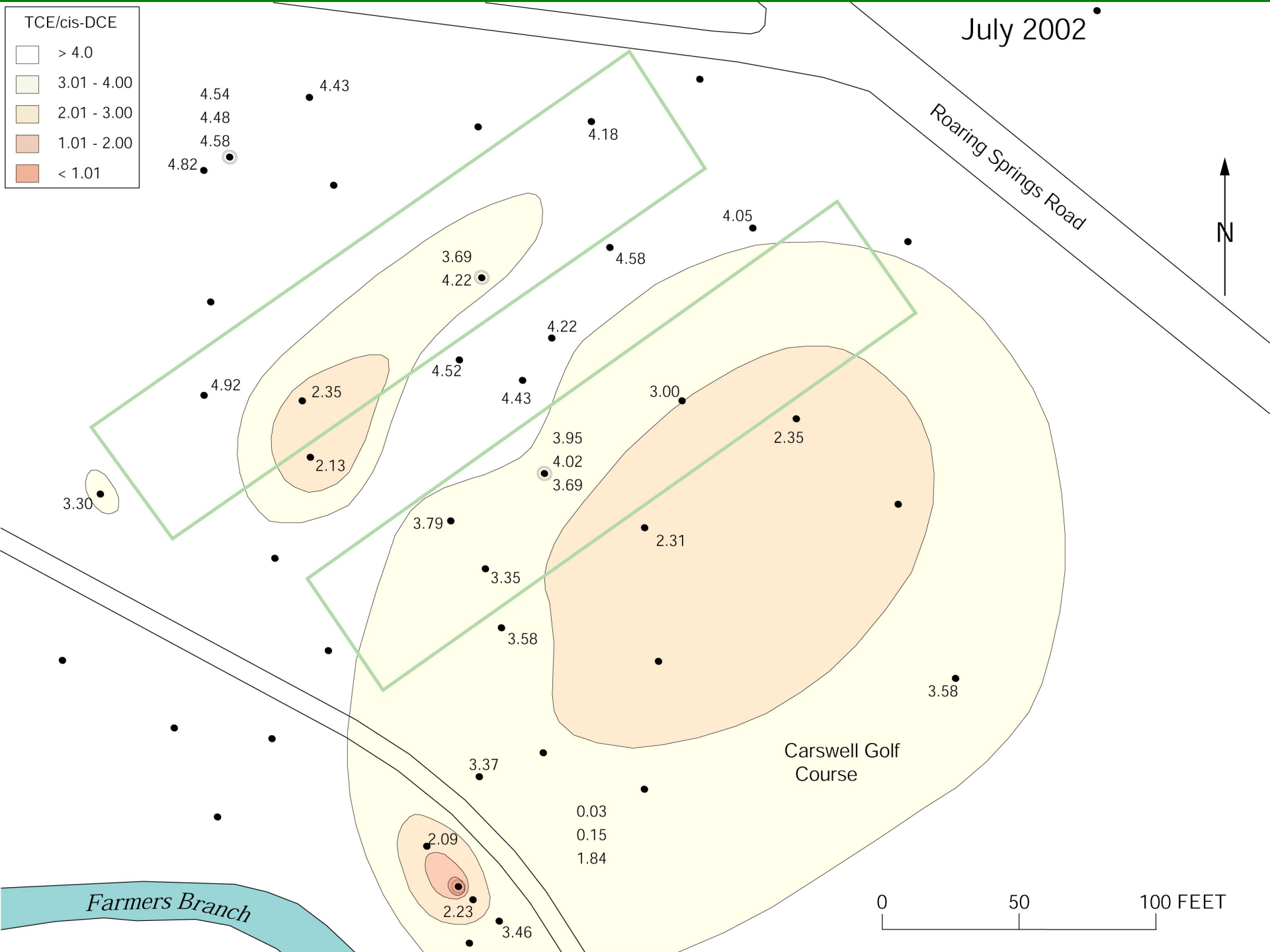
2.01 - 3.00
1.01 - 2.00
< 1.01
January 2002
Roaring Springs Road
N
3.35
4.04
4.67
4.18
3.83
3.69
2.30
3.58
4.18
3.69
3.92
3.19
1.88
4.25
2.78
2.79
1.51
0.22
3.89
3.58
3.35
3.59
0.47
3.00
3.32
2.85
Carswell Golf Course
2.64
0.07
0.54
1.32
1.55
2.21
2.52
1.01
Farmers Branch
0
50
100 FEET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> 4.0
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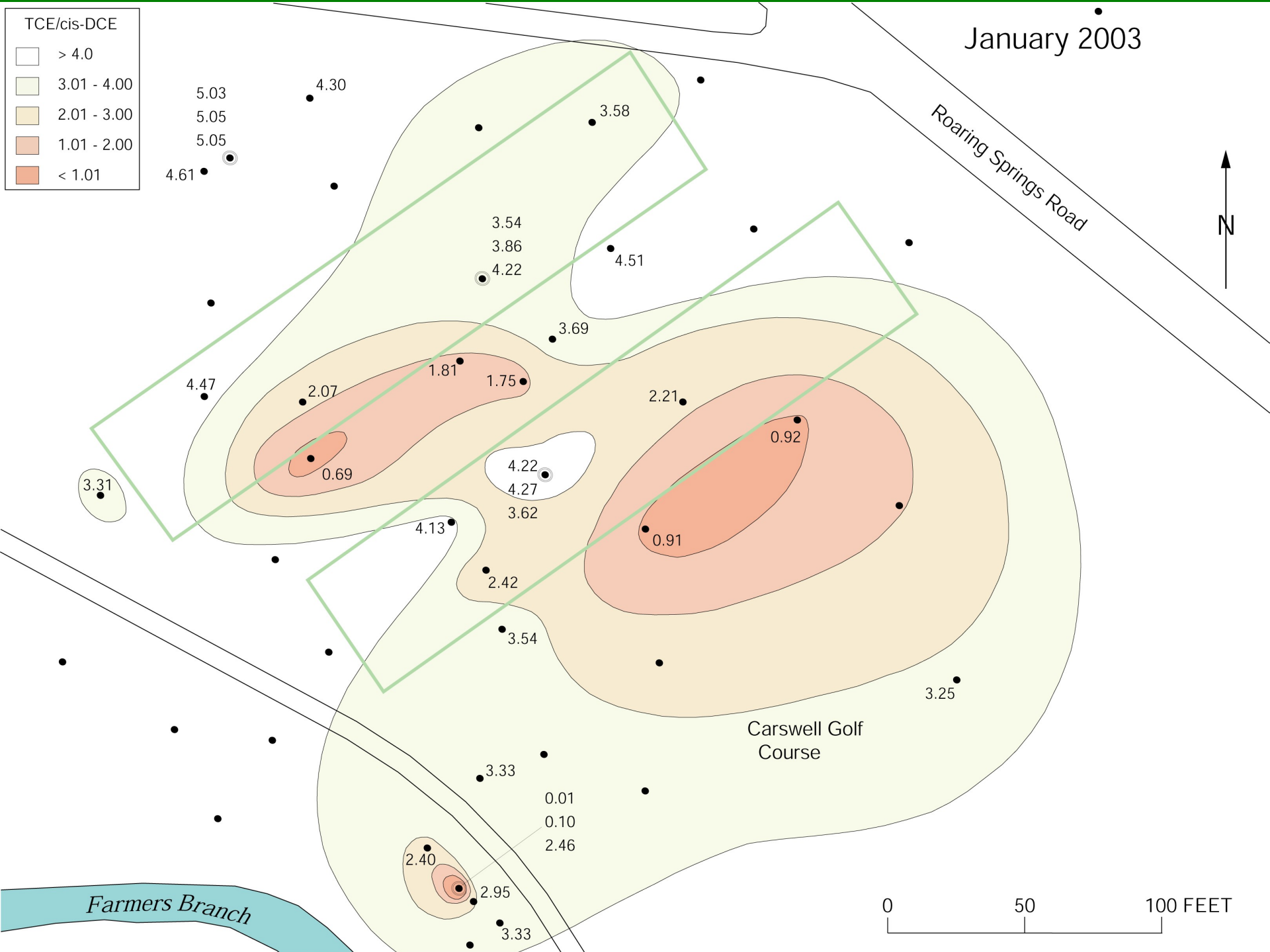
2.01 - 3.00
1.01 - 2.00
< 1.01
July 2002
Roaring Springs Road
N
4.54
4.48
4.58
4.82
4.43
4.18
4.05
4.58
3.69
4.22
4.22
4.52
4.43
4.92
2.35
2.13
3.30
3.00
2.35
3.95
4.02
3.69
3.79
2.31
3.35
3.58
3.58
3.37
Carswell Golf Course
0.03
0.15
1.84
2.09
2.23
3.46
Farmers Branch
0
50
100 FEET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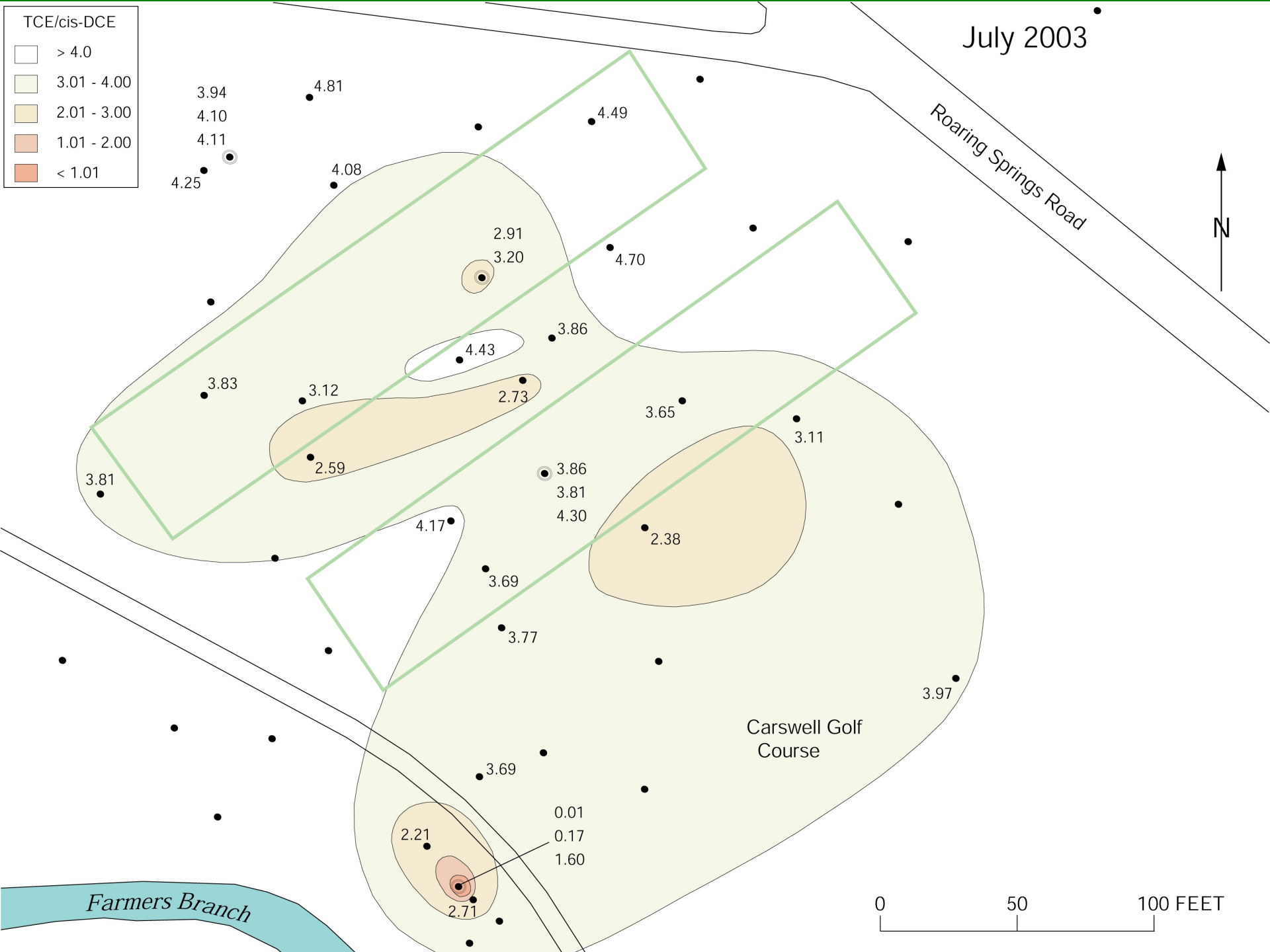
> 4.0
3.01 - 4.00
2.01 - 3.00
1.01 - 2.00
< 1.01
January 2003
Roaring Springs Road
N
5.03
5.05
5.05
4.61
4.30
3.58
3.54
3.86
4.22
4.51
3.69
4.47
2.07
1.81
1.75
0.69
2.21
0.92
3.31
4.22
4.27
3.62
4.13
0.91
2.42
3.54
3.25
Carswell Golf Course
3.33
0.01
0.10
2.46
2.40
2.95
3.33
Farmers Branch
0
50
100 FEET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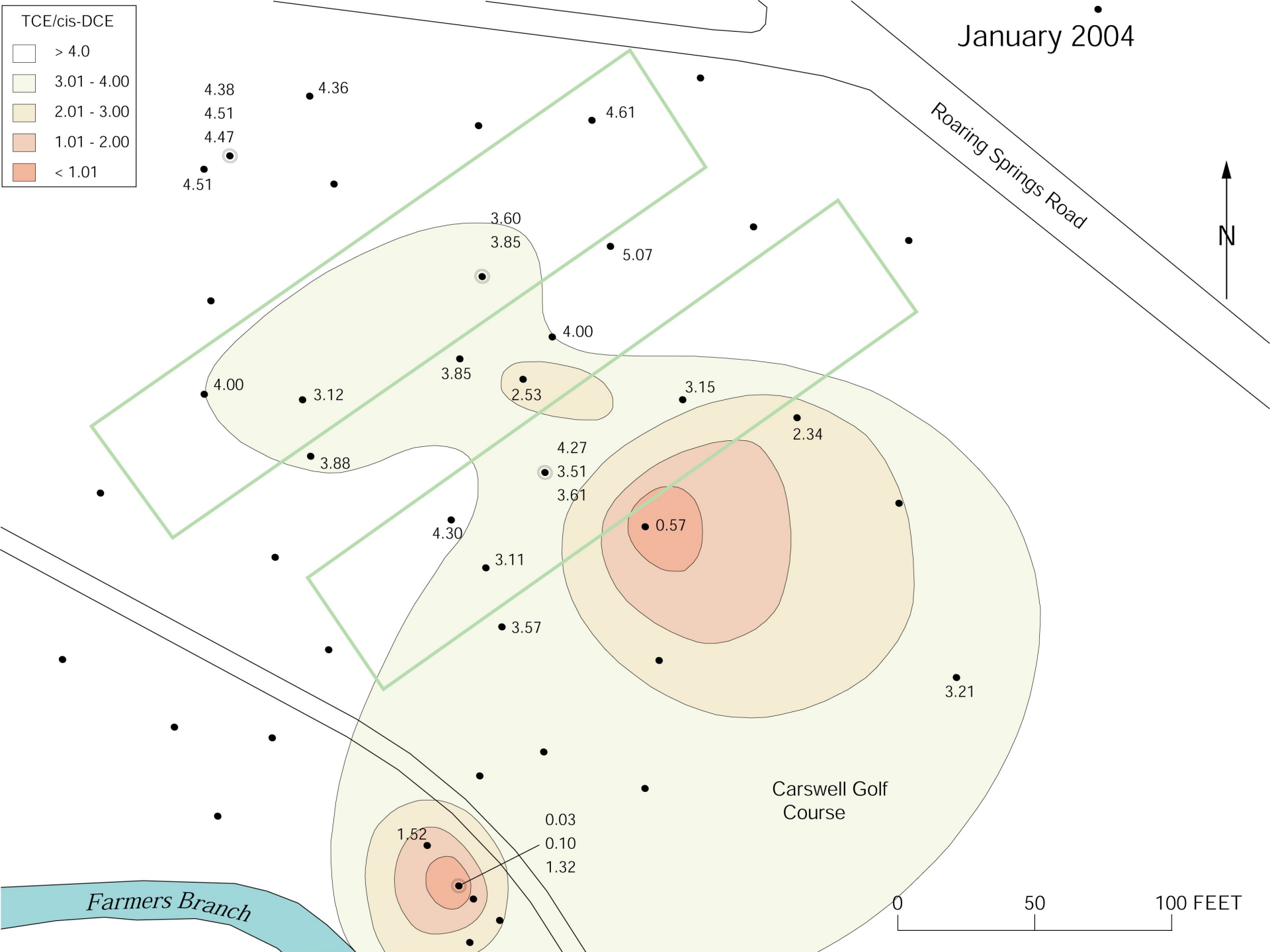
> 4.0
3.01 - 4.00
2.01 - 3.00
1.01 - 2.00
< 1.01
July 2003
Roaring Springs Road
N
3.94
4.10
4.11
4.25
4.81
4.08
4.49
2.91
3.20
4.70
3.86
4.43
3.83
3.12
2.73
3.65
3.11
2.59
3.81
3.86
3.81
4.30
4.17
2.38
3.69
3.77
3.97
Carswell Golf Course
3.69
0.01
0.17
1.60
2.21
2.71
Farmers Branch
0
50
100 FEET


TCE/cis-DCE
> 4.0
3.01 - 4.00
2.01 - 3.00
1.01 - 2.00
< 1.01
January 2004
Roaring Springs Road
N
4.38
4.51
4.47
4.51
4.36
4.61
3.60
3.85
5.07
4.00
4.00
3.12
3.85
2.53
3.15
2.34
4.27
3.51
3.61
3.88
0.57
4.30
3.11
3.57
3.21
Carswell Golf Course
1.52
0.03
0.10
1.32
Farmers Branch
0
50
100 FEET

Validated Process

Root growth results in changed redox condition
in the underlying aquifer, which promotes micr
mediated degradation of dissolved TCE

- Trees introduce labile organic matter into the aquifer
- Dissolved oxygen is subsequently consumed, creating
  iron reducing conditions
- Reducing conditions lead to reductive dechlorination of
  TCE in the aquifer

Performance

- Performance to Date:

- Roots at water table within 17 months
- Biodegradation rates increased from 0.0002/day to 0.02/day
- Increase in natural attenuation capacity of the aquifer from 0.004/m
- Potential decrease in plume stabilization distance from 9,700 to 160
-

Regulatory Issues

- Non-Native Vegetation
  (Testing robustness of native vegetation)
- Food-Chain Effect
  (Sampling vegetation)

Phytoremediation Web Sites

- http://www.gwrtac.org/html/tech_eval.html
  (Schnoor, J.L., 1997, Phytoremediation, Ground-Water Remediation Technologies Analysis Center Technology Evaluation Report TE-98-01)
- http://www.rtdf.org/phytodoc.htm
  (Comprehensive bibliography)
- http://www.engg.ksu.edu/HSRC/phytorem/
  (Links to other sites)

Closing Thought

…many problems, similar to the ones humans want to solve, have already been cracked by Mother Nature. Nature offers “a huge